ANALYSES AND AUDIT OF GROUNDWATER DATA
U.S DEPARTMENT OF ENERGY
URANIUM MILL TAILINGS REMEDIATION SITE
RIVERTON, WYOMING

Prepared for

Wind River Environmental Quality Commission
P.O. Box 217
Fort Washakie, WY 82514

Prepared by:

Maxim Technologies, Inc.
10601 Lomas NE, Suite 106
Albuquerque, NM 87112
Maxim Project No. 1690031

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MAXIM
TECHNOLOGIES INC

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LIST OF ACRONYMS

Acronym	Definition
ACLs	Alternate Concentration Limits
ALARA	As Low As Reasonably Achievable
ASTM	American Society of Testing and Materials
BLRA	Baseline Risk Assessment
CFR	Code of Federal Register
cm	Centimeters
COPC	Constituent of Potential Concern
DOE	U.S. Department of Energy
EA	Environmental Assessment
EPA	U.S. Environmental Protection Agency
FONSI	Finding of No Significant Impact
ft/d	Feet per day
ft/yr	Feet per year
GCAP	Groundwater Corrective Action Plan
IHS	Indian Health Service
JTBC	Joint Tribal Business Council
LHS	Latin Hypercube Sampling
LTSM	Long-Term Surveillance and Monitoring
Maxim	Maxim Technologies, Inc.
MCLs	Maximum Contaminant Levels
meq/Kg	Mill equivalent per kilogram
mg/L	Milligrams per liter
MNA	Monitored Natural Attenuation
MOA	Memorandum of Agreement
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
pCi/g	Picocuries per gram
$pCi/m^2/sec$	Picocuries per square meter per second
PEIS	Programmatic Environmental Impact Statement
QA/QC	Quality assurance/quality control
RAC	Remedial Action Contractor
Ra-226	Radium 226
RAP	Remedial Action Plan
SEO	State Engineers Office
SOWP	Site Observational Work Plan
T&E	Threatened and Endangered Species
TAGR	Technical Approach to Groundwater Restoration
TH-230	Thorium-230
Tribes	Shoshone and Northern Arapaho Tribes
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act
WREQC	Wind River Environmental Quality Commission
WSAP	Water Sampling and Analysis Plan

RESULTS OF ANALYSES AND AUDIT OF GROUNDWATER DATA
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URANIUM MILL TAILINGS REMEDIATION SITE
RIVERTON, WYOMING

1.0 INTRODUCTION

The Wind River Environmental Quality Commission (WREQC) representing the Shoshone and Northern Arapaho Tribes (Tribes) requested proposals for technical assistance in fulfilling three objectives: (1) review and audit data generated by the US Department of Energy (DOE) for the Uranium Mill Tailings Remedial Action (UMTRA) project site at Riverton, which is known locally as the Susquehanna Site; (2) evaluate the adequacy of the Baseline Risk Assessment (BLRA) for the Riverton site and review of applicable standards; and (3) determine whether DOE followed proper procedures during site remediation and has fulfilled its obligations at the site. While it is recognized that the site is locally referred to as the Susquehanna Site, this document will use the DOE terminology and refer to the site as the Riverton site. WREQC selected Maxim Technologies, Inc. (Maxim) as its contractor for these tasks.

1.1 Purpose

The purpose of this analysis and audit is to review the actions that DOE has undertaken to remediate groundwater that has been contaminated as a result of uranium milling activities at Riverton. The Tribes are specifically concerned about the existing groundwater contamination, incomplete knowledge of the risk associated with the contamination, the DOE's "natural flushing" plan to remediate the groundwater contamination, and the application of institutional controls over the next 100 years. The Tribes' objective is to ensure that all data and information about the Riverton site and associated contaminated groundwater are obtained and reviewed for understanding. This will allow the Tribes to act responsibly for present and future Tribal members, the Reservation populace, and the environment.

1.2 Scope of Data Review

WREQC and Maxim agreed upon the following scope:

- Review all available documents, technical reports, agreements, etc., and identify any apparent data gaps or discrepancies. A list of documents reviewed is provided in Section 7.
- After the review, a report of findings would be prepared and submitted to the WREQC as required in the scope of work.
- Maxim representatives would travel to WREQC offices to review the UMTRA files, obtain documents for the review/audit, and meet with appropriate individuals to discuss the scope of work.
- Maxim would obtain a copy of the DOE database containing all water quality data, soil/sediment data, monitor well information, and other pertinent data.
- With the exception of DOE, Surface Remedial Action Plan (RAP), 1987; DOE 1989; and DOE 1991, Maxim did not review any surface remediation data or reports.

1.3 Limitations

We have relied on existing data for this report; no new data were generated. This work was performed in accordance with the generally accepted practices of other consultants undertaking similar studies at this time. In completing this project, Maxim observed the degree of care and skill generally exercised by other consultants in the same field operating under similar circumstances and conditions. Maxim's findings and conclusions must be considered not as scientific certainties but as opinions based on our professional judgment concerning the significance of the data reviewed during the course of the evaluation. Other than this, no warranty is implied or intended.

2.0 BACKGROUND AND OVERVIEW OF CURRENT DOE RIVERTON UMTRA PROGRAM

2.1 DOE's Conceptual Model for the Riverton Site

The DOE's conceptual model of the Riverton UMTRA site is summarized in Figure 1, taken from Figure 4-2 of the Final Site Observational Work Plan (SOWP) for the UMTRA project Site at Riverton, Wyoming (DOE, SOWP, 1998a). The conceptual model is described in the following paragraphs.

The Riverton, Wyoming, UMTRA Project site is in Fremont County, two miles southwest of the city of Riverton and within the boundaries of the Wind River Indian Reservation (Northern Arapaho and Shoshone) on land now owned by the state of Wyoming. The population in the site vicinity is predominantly Native American. The UMTRA site is known locally as the Susquehanna Site. The nearest communities are Arapahoe and St. Stephens on the Wind River Reservation. The land around the site is mainly agricultural with the primary crop as hay grown on irrigated fields. The climate is arid; average annual precipitation is almost 8 inches (20 centimeters [cm]) and the average annual snowfall is almost 36 inches (91 cm). Cultural resources identified at the site are extensive and are considered eligible for listing on the National Register of Historic Places. No known threatened or endangered (T&E) species exist at the site (DOE, EA, 1998b).

Fremont Minerals, Inc., built the mill at the site in 1958 to treat the variety of ore types available in the area. Both acid and alkaline mill circuits were used because of the range of ore types. The initial mill capacity was 500 tons of ore per day, which increased to 450 to 500 tons per day in the acid circuit and 250 to 300 tons per day in the alkaline circuit by 1960 (Merritt, 1971). By 1960 the mill had been acquired by Susquehanna-Western, Inc. Sulfuric acid was produced from sour gas in an on-site production facility rated at 100 tons per day.

When milling operations ceased in 1963, about one million cubic yards (800,000 cubic meters) of tailings were stockpiled on 70 acres (30 hectares) southeast of the mill site. An additional 70 acres north of the tailings pile and 50 acres (20 hectares) southeast of the pile were also contaminated as a result of ore stockpiling, milling activities, and windblown tailings. About 1.8 million cubic yards (1.4 million cubic meters) of contaminated material was removed from the site during surface remediation activities and disposed of at Umetco's Gas Hills disposal site. Surface remedial action was completed in November 1989.

The Riverton site is on alluvial deposits between the Wind River, 1 mile (1.6 kilometers) to the north, and the Little Wind River, 0.5 mile (0.8 kilometer) southeast of the site. A sulfuric acid plant that was used during the former uranium milling is still in operation near the site boundary.

Two groundwater systems occur in the vicinity of the Riverton processing site. The uppermost aquifer consists of unconfined groundwater in the shallow alluvial deposits and the hydraulically connected semi-confined sandstone unit of the Wind River Formation. The second system contains confined groundwater in the deeper sandstone layers of the Wind River Formation. The DOE believes that the confined aquifer has not been affected by milling operations. Depth to water in the uppermost aquifer ranges from about 3 to 10 feet (1 to 3 meters) below ground surface. The aquifer has an average saturated thickness of 50 feet (15 meters). Groundwater in the uppermost aquifer flows predominantly to the south-southeast and discharges into the Little Wind River, approximately 2,800 feet (850 meters) downgradient of the site, to wetland areas east and southwest of the site, and to an Oxbow Lake formed southeast of the site when the river changed its course in 1994. The estimated groundwater velocity is 160 feet (50 meters) per year. Recharge to the uppermost aquifer is from precipitation, snowmelt, and seasonal irrigation ditches.

Contaminants associated with past milling operations have migrated downward into the unconfined shallow alluvial aquifer and, to a lesser degree, into the semi-confined groundwater in the underlying sandstone unit. Manganese, molybdenum, sulfate, and uranium are considered contaminants of concern at the Riverton site (DOE, EA, 1998b).

2.2 Overview of Current DOE Riverton UMTRA Program

The DOE is required to demonstrate that proposed groundwater cleanup actions at the UMTRA Project processing sites will comply with the U.S. Environmental Protection Agency (EPA) groundwater cleanup standards in 40 CFR 192, Subparts B and C. The need for groundwater restoration at selected UMTRA Project processing sites is determined based on the

EPA regulatory requirements for protection of human health and the environment. To ensure that technically and financially sound groundwater restoration activities are selected, the DOE has proposed the observational approach.

The observational approach uses existing site data to develop a conceptual model of site conditions and applicable compliance strategies. This information is used to develop a groundwater restoration program based on "most probable" site conditions. The most likely alternative scenarios are also postulated during the development of the initial groundwater restoration action plan. Contingency plans are required to be developed to deal with deviations from reasonably anticipated conditions. The observational approach is supposed to link a cost-effective remediation option with an effective contingency plan that will result in full regulatory compliance and protection of human health and the environment without the burden of excessive site characterization and conservatism (DOE, 1993).

Information on the contaminant sources, pathways, and receptors at a site is used to develop a conceptual understanding of the site to evaluate potential risks to human health and the environment. The conceptual site model should include known and suspected sources of contamination, types of contaminants and affected media, known and potential pathways for migration, and known or potential human and environmental receptors. This effort is to help in identifying locations where additional characterization will be necessary and in identifying potential groundwater restoration technologies.

2.3 DOE's Analysis of Human Health and Ecological Risk

The BLRA (DOE, BLRA, 1995) developed for the Riverton Site identified 24 chemicals that exceeded background (naturally occurring) concentrations. Fourteen of these constituents were eliminated from further evaluation because of low toxicity, low concentrations compared to high dietary intake or because concentrations were within nutritional ranges. Constituents were evaluated according to guidance provided in Appendix B of the Programmatic Environmental Impact Statement (PEIS) (DOE, PEIS, 1996). Results of that evaluation indicated that arsenic, manganese, molybdenum, sulfate, and uranium in the surficial aquifer could adversely affect human health if contaminated groundwater were used as the sole source of drinking water. The DOE believes that data collected after completion of the BLRA further support this conclusion, although contaminant concentrations are interpreted to have decreased with time. Manganese, molybdenum, and sulfate present a potential non-carcinogenic risk; uranium and, to a lesser extent, arsenic present a carcinogenic risk.

After further evaluation of data, including results of the 1997 round of sampling (DOE, SOWP, 1998a, Appendix B2), arsenic was eliminated as a constituent of potential concern (COPC) because concentrations are interpreted to have decreased through time and to be currently within the historical range of background values. The remaining constituents (manganese, molybdenum, sulfate, and uranium) are considered COPC with respect to human health at the Riverton site.

A screening-level ecological risk assessment was conducted to qualitatively evaluate ecological risks associated with contaminated groundwater. The first phase of that assessment is documented in Section 7 of the BLRA (DOE, BLRA, 1995) and is supplemented with additional data collected in 1995. Soils, sediments, and surface water were sampled at locations such as the Little Wind River, the Oxbow Lake, and wetland areas where groundwater intersects the land surface. Vegetation was sampled to evaluate root uptake of contaminants.

Contaminant concentrations were compared to benchmarks, such as livestock watering guidelines and the Wyoming water quality criteria, for protection of aquatic life. Contaminant concentrations in the surficial aquifer at the site are interpreted to be insufficient to present a risk to plants through root uptake. Molybdenum and sulfate in the groundwater could concentrate in the soil and build up to levels toxic to plants if contaminated groundwater were used continuously for irrigation. Molybdenum concentrations in groundwater could be detrimental to livestock if contaminated groundwater were used to irrigate forage plants. Sulfate concentrations in the groundwater exceed the level that EPA considers protective of livestock. Iron and uranium concentrations in the Oxbow Lake exceed the Wyoming water quality criteria for protection of aquatic life. However, the oxbow is expected to eventually fill in with sediment (DOE, EA, 1998b). Contaminants discharging into the Little Wind River from the surficial aquifer are diluted to background concentrations and, therefore, the DOE interprets them as presenting no risk to ecological receptors.

2.4 Groundwater Compliance

The proposed strategy to achieve compliance with EPA groundwater standards is natural flushing with institutional controls and monitoring over a 100-year duration. Geochemical and hydrologic data are cited in support of DOE's interpretation that contaminant concentrations will continue to decrease with time as the shallow, unconfined aquifer flushes toward the Little Wind River. Monitoring was proposed at 19 locations, and sample media consisted of groundwater, surface water, vegetation, and sediments. Institutional controls included supplying an alternative water supply, proposed restrictions on the use of groundwater in the contaminated portion of the uppermost aquifer system, and a proposed moratorium on well drilling permits issued for the affected area.

2.5 Regulatory Status (including National Environmental Policy Act [NEPA] and Institutional Controls)

The EPA groundwater standards (40 CFR 192) specify groundwater cleanup standards for DOE's UMTRA Project. One allowable method for achieving compliance with the groundwater standards is the use of natural attenuation or natural flushing. The DOE is allowed to use this approach provided that the contamination is reduced to specific levels within a 100-year timeframe. This approach is contingent on the implementation of adequate institutional controls to preclude exposure to contamination resulting from contaminated groundwater.

The DOE has selected natural flushing as the compliance strategy for the Riverton site. DOE maintains that the contamination will meet appropriate standards within 100 years and also asserts that it has implemented institutional controls.

An Environmental Assessment (EA) was finalized in September 1998. The DOE issued a Finding of No Significant Impact (FONSI) in September 1998. The DOE asserts in these documents that the selected groundwater compliance strategy would not result in significant impacts, and the implementation of the proposed action does not require an environmental impact statement.

3.0 RESULTS OF DATA AUDIT

The review and analysis by Maxim staff examined DOE calculation sets and resulting interpretation of aquifer hydraulic properties, contaminant fate and transport, groundwater flow modeling, risk assessment parameters, and exposure risks to human health and the environment. The Maxim staff and their areas of expertise are provided in Section 6. Specific tasks included the following:

- The site-specific Groundwater NEPA EA and a Groundwater Corrective Action Plan (GCAP) were reviewed. The review and analysis of site-specific technical reports produced by DOE and DOE contractors also included the BLRA, Surface Remedial Action Plan (Surface RAP), UMTRA Project Water Sampling and Analysis Plan (WSAP), and SOWP.

- The conceptual and analytical models used to make or support remediation recommendations for the site were reviewed.

- A review of proper "tiering" of the EA to DOE's PEIS for UMTRA Groundwater Project was completed.

- An evaluation of whether there has been adequate compliance with DOE regulations, orders, and guidelines for complying with NEPA at the Riverton Site was conducted.

- DOE's remedial action alternatives, including the no-action alternative, were technically evaluated.

- An assessment of cumulative and unavoidable and adverse environmental impacts was completed.

- The adequacy of institutional controls at this site was evaluated.

- Compliance with the Council on Environmental Quality's regulations for implementing the NEPA in Title 40, Code of Federal Regulations, Parts 1500 through 1508, was evaluated.

- A report including technical and scientific comments on the documentation reviewed was prepared for the WREQC.

A primary focus of review was the SOWP (DOE, SOWP, 1998a), since its function is to present the most recent understanding and data to support the selection of the remedial strategy for groundwater as presented in the GCAP.

3.1 Review of the Surface Remedial Action

At the request of the Tribes, WREQC, Maxim reviewed data presented in three DOE documents (DOE, Surface RAP, 1987; DOE, 1989; and DOE, 1991) to determine the nature of actions taken by the DOE at the Riverton site. Maxim's data review is limited to these materials, and no effort has been made to acquire other data sources to provide verification of stipulations made in these documents. Maxim also reviewed available actual raw and reduced data to determine whether actions taken in the field were appropriate based on interpretations of available data.

3.1.1 Verification Excavations as Described in DOE, Surface RAP, 1987

DOE cites EPA – promulgated standards (40 CFR § 192, subparts A, B, and C) that provide guidelines for excavation work to be performed at the Riverton Site. The following excerpts from Section II.A.1 and 3 in the DOE (1991) describe the Remedial Action Contractor's (RAC's) purpose and objective for the remedial work done at the site as based on the 40 CFR § 192. Relevant excerpts from Sections II. A. 1 and 3 read:

"1. <u>Purpose and Objectives:</u>

The design objectives are to isolate the uranium mill tailings for the purpose of preventing their misuse by man and dispersal by natural forces, and to protect the groundwater by removing all contamination from the Processing Site to eliminate any infiltration. The following major design objectives were established:

- *Reduce contaminant levels of Radium 226 (Ra 226) in areas released for unrestricted use to 5 picocuries per gram (pCi/g) averaged in the first 15 cm of soil* *below the surface, and 15 pCi/g averaged in 15-cm-thick layers of soil below more than 15 cm below the surface....*

3. *Environmental Requirements:*

- *The design shall be based on reducing the average radon flux from the site to levels not exceeding 20 picocuries per square meter per second (pCi/m2/sec).*
- *The contaminant levels around the Riverton Site shall be reduced to levels which do not exceed 5 pCi/g of Ra 226 above background in the top 15 cm of soil and do not exceed 15 pCi/g Ra-226 above background in any 15 cm layer below that depth...."*

Volume 3, Appendix J of the *Final Completion Report* contains 14 verification grid drawings and corresponding radiological verification data that document areas in the site that met the 5 and 15 pCi/g Ra-226 standards for soil discussed above. Maxim reviewed the data associated with these areas and found no excursions above the standards when the verification readings were added to the background soil concentrations reported in DOE (1991) of 1.9 pCi/g Ra 226 in the Riverton area.

3.1.2 Verification Excavations as Described in DOE (1989) (Application of Supplemental Standards)

Contaminant removal at the Riverton Site resulted in the development of excavation protocols for Thorium-230 (Th-230) that was discovered at depth in portions of the site. Specifically to pages 1 and 2 which are excerpted below, DOE (1989) discusses modifications to the original RAP developed for the site as authorized by Subpart C of 40 CFR § 192 and discussed specifically in 40 CFR § 192.21(f). This portion of the code allows for excavation of Th-230 to levels that are As Low As Reasonably Achievable (ALARA). Excavation to ALARA levels instead of the 5 and 15 pCi/g in top 15 cm of soil and subsequent 15 cm intervals, respectively, resulted in the following changes to the RAP:

"...Supplemental standards may be applied when thorium-230 (Th-230) contamination is present in the absence of excess Ra-226. The need for excavation of this material will be determined by comparing the Th-230 concentration to a guideline equivalent to the Ra-226 standard. This guideline is

based on the residual Ra-226, corrected for decay and the Ra-226 ingrowth from Th-230. If the guideline is exceeded, the Th-230 will be excavated to levels that are as low as reasonably achievable (ALARA). ALARA conditions at the Riverton site will be met by excavating the material above the saturated zone to the Th-230 guideline and leaving in place, within the saturated zone, any Th-230 contamination above the guideline. Supplemental standards will be applied to the excess Th-230 contamination left in the saturated zone."

The DOE also modified the RAP with the following language:

" For areas in which a significant fraction of the material being sampled is rock or gravel, the nine-plug composite 30x30 foot grid may be collected by using a shovel to take bulk samples, separating the fines from the rock using a #4-mesh screen and determining the weight of the fines and rock fractions. The fines shall then be counted for Ra-226 following the standard RAC-015 specifications and quality controls. The resulting radium concentration will be corrected to a final, reportable concentration utilizing the mass ratios of the rock/fines fractions.

...Grid-by-grid results for thorium analyses (corrected for the rock/fines fractions, as above) shall be compared to a Th-230 guideline, which is equivalent to the Ra-226 standard. This guideline is based on the residual Ra-226 corrected for decay, and the Ra-226 ingrowth from Th-230. Grids or groups of grids exceeding the 35 pCi/g guideline shall be excavated to the level of the saturated zone. The level of the saturated zone shall be determined utilizing available field data.

...<u>For areas excavated to or below the level of the saturated zone, reporting of analysis results is not necessary prior to backfill.</u>

...Supplemental standards will be applied to residual radioactive material in the saturated zone exceeding 35 pCi/g Th-230 based on the criteria in 40 CFR 192.21 paragraphs (b) and (f). Estimated area, volume, and average concentration will be documented in the site completion report."

In addition to the aforementioned changes, Attachment 1 of the RAP discusses operational concerns and other reasons for the changes made. Signatories to the Attachment include representatives of DOE, the Nuclear Regulatory Commission (NRC) and the State of Wyoming.

According to DOE (1989), the changes were made to simplify construction and avoid expenditures, which would be high relative to long-term benefits of proceeding under the work plan originally specified in the RAP. The change to the RAP would result in low-level contaminated material remaining in portions of the saturated zone of the subsurface soil that, according ~~to~~ DOE (1989), would result in an average radon flux of 0.4 pCi/m^2/sec after 1,000 years. Two questions remain after reading the report:

- What is the radon flux from the specific areas affected by excavation to ALARA levels (i.e., not averaged over the whole site)?

- What are the radon flux levels from the ALARA areas in the interim (over the next 1,000 years)?

The following discussion will focus on conditions in the field after completion of work as described in the RAP (DOE, Surface RAP, 1987) and Attachment 1 to the RAP at the Riverton Site (DOE, 1989). Volume 3 in DOE (1991) discusses Post-Remedial Site Conditions in Appendix H. In the as-built condition, the following quantities of soil were reportedly handled:

- 1,792,630 cubic yards of contaminant, excluding vicinity properties, were relocated to the Gas Hills site

- 585,870 cubic yards of uncontaminated (<5 pCi/g) soil were backfilled and contoured

Supplemental standards for soil containing Th-230 in the absence of Ra-226 were applied to soil, at depth, and within the saturated zone in 231 verification grids, which represents approximately 6.8 percent of the total number of grids (Figure 2).

Appendix J of Volume 3 in DOE (1991) discusses verification measurements in general, and discloses the fact that portions of the site were remediated as vicinity properties. These areas include area N (Figure 2) and portions of the other areas that were not indicated graphically on any of the figures reviewed. According to DOE (1991), of the 1,792,630 cubic yards of contaminated material removed from the Riverton Site, vicinity property material accounted for 184,984 cubic yards. Maxim reviewed the data package inventory, which indicated that information on vicinity properties had been forwarded but those data were not located.

Page 2 of Appendix J, Section A discusses in further detail how supplemental standards for Th-230 ~~were~~ applied at the site.

> *"A concentration of 35 pCi/g Th-230 was selected to insure that, after 1,000 years, the decay of Th-230 to Ra-226 would not exceed the subsurface limit EPA limit of 15 pCi/g."*

The 35 pCi/g Th-230 is referenced in Volume 1 of DOE (1991), Section D1, as a "DOE guideline". The 35 pCi/g value is not a guideline but supplemental standard.

Table J.4 of Appendix J lists 423 grids on the site in which Th-230 concentrations were adjusted. As discussed earlier, multiplying laboratory Th-230 measurements by the fines/cobble ratio resulted in the corrected Th-230 concentration for the entire sample volume. This representation evidently relies upon the assumption that the coarse fraction of the sample contained no contaminant. Maxim was not able to discern whether this is an accurate representation from the conditions as specified in the report. As a result, the question whether the coarse fraction of the samples was completely devoid of Th-230 persists, as well as the question about whether ignoring the potential for Th-230 on the coarse fraction results in underestimation of the Th-230 levels remaining on site.

Two grids, H-45-11 and H-45-16 (Figure 2), were identified in Table H-4 of DOE (1991) as

"exceed(ing) the 15 pCi/g (plus background) Ra-226 standard, after rocks-to-fines correction was applied to the Ra-226 and Th-230 values and the values were projected to 1,000 years to produce a Ra-226 estimated concentration. Resultant 1,000 year concentrations were 22.2 pCi/g and 19.5 pCi/g, respectively."

DOE decided to allow the grids to remain unexcavated despite the exceedances and

"noted that the backfill diffusion coefficient used in the calculation is derived from density values for a compacted soil, however the DOE feels that the use of this coefficient is applicable due to compaction by heavy equipment traffic on site during backfill placement operations."

Maxim was unable to determine whether soil compaction criteria prerequisite for application of the coefficients discussed in the previous sentences are actually called out in DOE guidelines, and the reviewed documents are unclear about how soil was placed in the areas of grids H-45-11 and H-45-16. The radon flux results estimated from these two sites, including DOE default fill compaction figures, were 3.6 and 3.1 pCi/m^2/sec, respectively. The estimates are not warranted due to the nature of the assumptions.

Maxim was not able to locate a specific reference to Table J.5, (*Appendix J in DOE [1991]*) in any of the completion report documents. Section D 1, of *Volume 1* in DOE (1991) refers to

"...Separate analytical result tables are provided in Appendix J, Part A...for verification grids where excavation to the saturated zone was performed (supplemental standards)"

Without text referring to the information presented in the table, the exact nature and purpose of the data in Table J.5 remains unknown.

3.2 Hydrogeology

The groundwater compliance strategy for the Riverton site is passive remediation through natural flushing coupled with institutional controls to limit exposure to the contaminated groundwater, and verification monitoring to ensure the forecasts are accurate (DOE, EA, 1998b). This strategy is also known as Monitored Natural Attenuation (MNA). As defined by EPA and cited by DOE's guidance on MNA (DOE, 1999b), MNA is:

> *"... the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup, to achieve site-specific remedial objectives within a time frame that is reasonable as compared to those offered by more active measures."*

DOE's time frame for the Riverton site is 100 years. The EPA UMTRA groundwater regulations (40 CFR 192) allow for a natural flushing period of up to 100 years. For an additional discussion on this topic, please see Section 3.5, Institutional Controls and Regulatory Issues, of this report.

The DOE's MNA compliance strategy focuses on the uppermost unconfined aquifer system, excluding the semi-confined and confined. Review of the analytical data suggests that the uppermost, unconfined aquifer is not the only aquifer that may pose a risk. It appears the quantity of monitor wells in the three aquifers, the spacing of the wells, and the overall understanding of the stratigraphic relationships between the aquifers and aquitards may be insufficient to support the MNA compliance strategy. The decision to model only the uppermost, unconfined aquifer appears to be based on the existing data (number of wells, historical analytical results, etc.) that suggest only the surficial aquifer is contaminated enough to pose a risk to human health or the environment. However, this could be seen as a circular argument, in that unless an independent standard is applied to the level of characterization, the current level of investigation (i.e., well density) could be seen as selectively in support of MNA. What is a reasonable independent standard for the level of investigation and how much additional work would be needed to meet that standard? These questions are addressed in the following sections.

3.2.1 Monitoring Well Spacing

The SOWP defines the hydrogeologic setting (or conceptual model) of the site as consisting of two hydrologic systems consisting of five distinct hydrostratigraphic units. The first hydrologic system consists of (1) a surficial unconfined alluvial and sandstone aquifer, (2) a leaky shale aquitard, and (3) a semi-confined sandstone aquifer. The second hydrologic system consists of (1) a second, more impermeable shale aquifer and (2) a confined sandstone aquifer (Figure 1). Coarser grained sandy paleochannels cutting through the silt and shale zones are documented in the literature for this type of formation (Seeland, 1978). All of these units, except for the uppermost, unconfined aquifer, are part of the Lower Eocene Wind River Formation, a sequence of sand, silt and shale deposited in an ancient alluvial-fluvial environment.

The effectiveness of the MNA compliance strategy depends on the extent to which each of these geologic units is understood in the conceptual model. To develop the model, each of the water-bearing units, as well as the aquitards, should have been defined by wells that included lithologic logging as a basis for the stratigraphic interpretation and by groundwater analyses that will define plume boundaries and migration over time. A complete understanding of the lithologic heterogeneity inherent of the formation (such as paleochannels) is not evident in the geologic logs because well spacing was inadequate. The presence of paleochannels could create preferential flow paths that would result in higher contaminant concentrations along those paths.

Figure 3 is a geologic cross section based on four monitoring wells (RVT-110, 106, 704 and 701). The cross section extends from northwest to southeast, from Well 110, located upgradient from the former tailings pile and completed in the confined sandstone aquifer, to Well 701, located near the Little Wind River and completed in the shale and siltstone of the aquitard beneath the surficial aquifer. Wells 106 and 704 are between the two end wells, with Well 106 located about 300 feet from Well 110 (forming essentially one data point within the large overall aerial extent of the plume). The length of the cross section is approximately 4,700 feet, yet there are only four data points along the section with about 3,000 feet between Wells 110 and 704 and approximately 1,500 feet between Wells 704 and 701. The cross section depicts relatively continuous, tabular sand and shale units in the subsurface. This is mainly due to an overly broad interpretation not supported by data.

The only indication of a paleochannel in the cross section is a sandstone body intersected by Well 106. The sand body might be interpreted as a paleochannel approximately 18 feet thick and 500 feet wide. However, with only a single cross section, the three-dimensional characteristics of the sand body and other sand and shale beds cannot be determined. In fact, the lateral dimension of 500 feet in the southeast direction for this particular sand body is strictly fictitious, since the single well that intersects the sand body (Well 106) defines the lateral extent. Further, the possible presence of other subsurface paleochannels in the thickly bedded aquitard cannot be determined. In essence, there are not enough monitor wells to effectively characterize the hydrogeologic environment.

An example of the problem of inadequate well spacing and the potential for missing sand paleochannels within the shale beds can be found in Cross Section A-A, which shows Well 110 completed in the thick tabular shale aquitard that separates the confined zone from the semi-confined zone. Review of the lithologic log for Well 110 reveals that the well is actually screened in silty sandstone not shale. Further, Well 110 is designated in the SOWP as a confined zone background well but, in fact, it is completed in what is defined on the cross section as the "confining shale aquitard". This suggests that even if the well is completed in a water-bearing zone, it is a thin sand zone within thick shale approximately 30 feet above the top of the confined zone. As such, it is not likely to be representative of the confined aquifer conditions.

The problem of inadequate well density is again illustrated by reviewing the location map of the wells in the surficial aquifer (Figure 5). There are only four monitor wells in the approximate one-square mile of impacted surficial aquifer downgradient of the former tailings pile. This very low density of monitoring locations is insufficient to rule out the possibility that much higher concentrations of constituents than those that have been observed to date exist in preferential flow paths that are likely present in these fluvial and alluvial materials (Seeland, 1978). Aerial photographs (Figure 4) indicate the abundance and scale of fluvial and alluvial channels that may be serving as preferential flow paths at the site. The significance of this data gap can be seen in the DOE's interpretation of contaminant movement in the surficial aquifer (DOE, SOWP, 1998a).

"Contaminant movement through the surficial aquifer was evaluated by observing molybdenum, sulfate, and uranium concentrations throughout the site and southeast to the Little Wind River... Monitor Wells 101, 722, and 707 were chosen for the evaluation because they approximately parallel the flow direction from the site to the Little Wind River. Slightly elevated contaminant concentrations were detected in samples from Monitor Well 101, which is located upgradient of the former tailings pile, but downgradient of the former ore storage area... Contaminant concentrations in groundwater from Monitoring Well 722, located directly downgradient of the site, are higher than those of Monitor Well 101... An evaluation of contaminant concentrations in groundwater from Monitor Well 707 over time indicates increasing concentrations of molybdenum. .... Water from this well generally exhibits the highest contaminant concentrations associated with the surficial groundwater in the site area. These concentrations indicate that the centroid of the contaminant plume is most likely near the well and migrating toward the Little Wind River."

A potential difficulty with this interpretation is that Well 722 may be located in a zone that significant contamination has bypassed due to preferential flow paths. If this is true, DOE's conceptual model of the site (i.e., that the centroid of the plume is near Well 707) may be in error because other surficial aquifer monitor wells are located thousands of feet away from the critical area surrounding Well 722 (Figure 6).

Based on the existing data from the semi-confined aquifer, the DOE concludes that contamination is present but the concentrations are below EPA Maximum Contaminant Levels (MCLs) protective of drinking water use and, therefore, do not pose a risk. This conclusion is based on analyses from only three wells downgradient and several wells sidegradient of the former tailings pile. This conclusion may be erroneous because of the inadequate well density and lack of spatial data. For example, well spacing is on the order of 1,800 feet between Wells 723 and 721 and 1,400 feet between Wells 723 and 719. In viewing the DOE (SOWP, 1998a) map depicting the monitor wells completed in the semi-confined aquifer (Figure 7), the paucity of wells is evident, especially in the areas northeast, west and southwest of Well 701. The lack of wells and resulting insufficient groundwater data demonstrates the inadequacy of characterization and weakens the support of MNA. Contaminant concentrations in the semi-confined aquifer could be greater than those seen to date and might, in fact, pose a risk equal to or greater than that posed by contaminants in the surficial aquifer. Unfortunately, the existing data are too sparse to determine what contaminant concentrations are throughout.

In a related observation, the DOE states that existing data demonstrate that the confined aquifer has remained uncontaminated by uranium milling at the site. The DOE cites Wells 726, 110, and 709 to support this statement. The information presented for these wells does not provide assurance there is no contamination in the confined aquifer for the following reasons:

- Monitor Well 726 is located offsite and upgradient (i.e., this monitor well has a near zero probability of being impacted by site-related contamination).

- Monitor Well 110 is on-site but upgradient of the primary contaminant source (the tailings pile) and, therefore, has a very low probability of being impacted by site-related contamination.

- Monitor Well 709 is more than 2,000 feet downgradient in finer-grained material than the surficial aquifer, making it unlikely that any site-related contamination could have come this far in the time since processing began.

There are not a sufficient number of sampling points in the confined aquifer to determine whether or not it has been impacted by site-related contamination. Given that (1) the DOE's conceptual model implies a downward, density-driven plume and (2) landowners are pumping water from the confined unit, thereby (3) increasing the possibility that site-related contamination might find its way into deeper units, the three monitor wells cited are not strategically situated to provide data to answer this question. The DOE's conceptual model shows a plume driven downward by recharge and laterally by regional flow. Landowners pump water from the confined unit, potentially inducing additional downward plume migration into the confined aquifer. Three monitor wells are not adequate to assess the risk of contamination in the confined aquifer. DOE did not install monitor wells most likely to intercept the confined aquifer in locations having the highest probability of receiving groundwater contamination (e.g., beneath or just downgradient of the former tailings pile location).

Information indicates that the confined aquifer is composed of a series of alternating sandstone and shale interbeds (Figure 3). No distinction was made among water-producing units of the confined aquifer. Water quality from wells completed within the contamination plume was compared to water quality in background wells. There is no information to indicate whether domestic wells that were sampled (if any) were completed in the uppermost water-producing unit of the confined aquifer (the most likely to be contaminated) or in some lower unit.

DOE has provided guidance for utilizing MNA (DOE, 1999b). The guidance states the following with respect to well spacing:

> *"The density of sample locations should be determined on the basis of the scale of heterogeneities in the conceptual site model, i.e., spacing should be on the same order of the dimensions of significant features of the conceptual site model. Additionally, spacing should provide for a sufficient number of samples to meet the acceptable level of uncertainty for data on critical characteristics."*
>
> *"If specific anomalies are present within the management zone that may have unusual or unknown effects on attenuation or transport (e.g., faults, unique geologic features, potential sources of other chemical releases), additional sample points should be added proximate to those anomalies. It is also important to install monitoring stations at the interface between media on a pathway (e.g., the point where groundwater discharges to surface water and losing reaches of water ways)."*

While it is recognized that the MNA guidance was issued after the majority of the wells were installed at the Riverton Site, the well spacing used for the Riverton site does not comply with DOE's MNA guidance because of an insufficient number of samples to meet the acceptable level of uncertainty for data on critical characteristics. In addition, wells in the surficial aquifer are on the order of 1,000 to 2,000 feet apart, and it is likely that this well spacing has missed critical paleochannels that provide preferred contaminant pathways. Wells in the semi-confined aquifer display a similar wide spacing. There is also insufficient well coverage near the Little Wind River. Wells in the confined aquifer are sparse (only three wells), yet these three wells are the basis for concluding that the confined aquifer has not been impacted. Local residents are currently utilizing the confined aquifer downgradient of the UMTRA processing site. Compliance with DOE's MNA guidance would necessitate an increase in well density to the extent that specific anomalies such as paleochannels can be recognized and understood in terms of their potential effects on contaminant concentration and transport. For example, if paleochannels average 100 to 200 feet across (Seeland, 1978), then well spacing should have been a maximum of 100 to 200 feet apart.

3.2.2 Discharge to the Little Wind River and Groundwater Flushing Velocity

The Conceptual Model provided in the SOWP (DOE, SOWP, 1998a) (Figure 1) depicts the contaminants in both the surficial and the semi-confined aquifers as discharging upward into the Little Wind River. DOE contends that the surficial aquifer discharges to the river (when the flow is not reversed by water in the irrigation canals) by referring to survey data. However, the survey data supporting this contention are not presented in the SOWP and, therefore, cannot be independently reviewed at this time. Assuming that the surficial aquifer always discharges to the river, the evidence used to conclude that the semi-confined aquifer also discharges into the river is not provided. At some depth the groundwater no longer discharges into the river and must flow downgradient under the Little Wind River channel. The depth at which groundwater no longer discharges into the river but flows downgradient to the other side of the river where it can be accessed by wells has not been adequately addressed by DOE.

The surficial aquifer has a calculated average groundwater velocity of 455 feet per year (ft/yr) (DOE, SOWP, 1998a, Section 4.3.1, p. 4-19); whereas the semi-confined aquifer has an average velocity of 175 ft/yr (DOE, SOWP, 1998a, Section 4.3.1, p. 4-22) (highest rate in a range of 0.175 to 175 ft/yr). Thus, the average groundwater velocity in the semi-confined aquifer is 2.6 times slower than in the surficial aquifer. If the duration of natural flushing to the Little Wind River in the surficial aquifer were 100 years, then the water in the semi-confined aquifer would take 260 years to flush an equal distance. This suggests that even if the contaminant concentrations in the semi-confined aquifer are lower than those in the surficial aquifer (an unsupported assumption), the contaminants may pose a risk due to the longer residence time in the aquifer. There are insufficient data to determine the flow path of the water in the semi-confined aquifer to clearly confirm or refute the concept that this water flushes to the Little Wind River along with the water in the surficial aquifer.

The hydrogeologic conceptual model does not adequately describe vertical gradients between the aquifers. The SOWP (DOE, SOWP, 1998a) states that the similarity between water levels in the semi-confined and surficial aquifers is the basis for believing that these aquifers are interconnected (Figure 8). However, Figure 8 illustrates water levels in the semi-confined and the confined aquifers are equally similar. For example, water levels in nested Wells 108 (semi-confined) and 110 (confined) respond in tandem in data taken on the same day. In this location the confined aquifer appears to always have a slightly higher head than the semi-confined aquifer, supporting the DOE's contention that the confined aquifer remains uncontaminated and a vertical, upward gradient exists between these two units. However, at the far downgradient location (Well 705 [semi-confined] and 709 [confined]), there are dates when heads in the confined aquifer are as much as 15 feet below heads measured in both the surficial and the semi-confined aquifers. The DOE apparently attributes these head differences to deep well pumping at the Koch Sulfur Products Plant. However, it is very unlikely that the head in well 709 is being so strongly influenced by the pumping of wells located over a mile away. Evidence of head differences between the two wells might as readily imply that the head in the confined aquifer is being drawn down across the site, providing a downward gradient from overlying aquifers and allowing contamination to move into the confined aquifer. Existing data are insufficient to support either contention.

3.3 Fate and Transport

3.3.1 Migration of Plume Beneath Little Wind River

As stated above, a significant issue related to contaminant transport is DOE's conclusion that contamination does not move beneath the river to groundwater in the inhabited area on the opposite side of the Little Wind River from the UMTRA site. The data presented by DOE do not completely support the conclusions made in the SOWP. DOE has ignored data tending to show migration of contaminants under the Little Wind River by oversimplifying the hydrogeologic characteristics of the "uppermost aquifer."

In its conceptual model, the DOE combines the surficial and the semi-confined aquifer together as the "uppermost aquifer" and then proceeds to focus on the surficial aquifer in its demonstration that contamination could not move beneath the river.

> *"The 1995 topographical survey shows that groundwater levels in surficial aquifer wells located on both sides of the Little Wind River are higher than the water level in the river. As a result, it is unlikely that the contaminant plume is migrating beneath the Little Wind River to affect the water quality on the south side of the river".* (DOE, SOWP, 1998a)

This quote means that the DOE believes that since water levels measured during discrete events are higher in groundwater than water levels in the river at the same time; that groundwater is always flowing to the river, providing a barrier to movement of groundwater across the river.

The DOE believes the fact that groundwater from Well 706, completed in the surficial aquifer on the opposite side of the Little Wind River from the UMTRA site, is more similar to river water than plume water constitutes evidence that it is unlikely contaminated groundwater has migrated beneath the river. This is depicted in a tri-linear diagram (Figure 9). However, the similarity of groundwater in Well 706 to river water could be taken as evidence that the river discharges to groundwater (i.e., that Well 706 is sampling water that has moved from the river to the groundwater), implying the surficial aquifer may not always discharge to the river and contamination could migrate beneath the river. There are insufficient groundwater data from the opposite side of the Little Wind River from the UMTRA site to determine if groundwater is migrating under the Little Wind River to the inhabited area on the opposite side.

The diagram of the conceptual model (Figure 1) shows both the surficial and the semi-confined aquifers discharging upwards to the Little Wind River. However, in the well cluster downgradient of the UMTRA site and closest to the river (Monitor Wells 705 and 707), the gradient is still shown as moving down from the surficial aquifer to the semi-confined aquifer (Figure 8). This configuration suggests that there is a possibility that contamination could migrate under the river in the semi-confined aquifer. There is evidence, seen in groundwater quality data taken from Monitor Well 735, completed in the semi-confined aquifer on the opposite side of the Little Wind River from the UMTRA site, that such migration may be occurring. Figure 10 presents plume maps of sulfate concentrations in the semi-confined aquifer, which shows the sulfate plume as defined by the 500 milligrams per liter (mg/L) isopleth. The 500 mg/L isopleth, using both 1993 and 1997 data, is shown as closed and entirely on the UMTRA side of the river. Note that while Monitor Well 735 is not shown on Figure 10; data included in Appendix B2 of the SOWP (DOE, SOWP, 1998a) indicate that Monitor Well 735 had a sulfate concentration of 572 mg/L in February 1996. Thus, the 500 mg/L sulfate isopleth should extend across the river and include Well 735. In addition, sulfate concentrations have been well above 500 mg/L in two of the three subsequent samplings of Monitor Well 735. The SOWP indicates that measured sulfate concentrations representative of background conditions in the semi-confined aquifer range from 141 to 220 mg/L with a median concentration of 170 mg/L (five observations). Sulfate concentrations reported in Monitor Well 735 range from 390 to 647 mg/L with a median concentration of 584 mg/L (four observations). These data suggest that groundwater from Monitor Well 735 has been impacted by at least sulfate contamination and indicates that contamination has migrated beneath the river. Without information from additional wells installed in the semi-confined aquifer on the opposite side of the Little Wind River from the UMTRA site, it is impossible to determine if contaminants have migrated or are migrating under the Little Wind River.

3.3.2 Oxbow Lake

DOE's concentration contour maps present contradictory interpretations of site conditions, creating additional difficulty related to interpretation of contaminant distribution. For instance, Figure 5 shows groundwater flow directly into the Oxbow Lake from the plume area. Surface Water Sample 747 from the Oxbow Lake has chemistry very similar to the highest values of the plume, but the sulfate, molybdenum, and uranium plume maps shown on Figures 6, 11, and 12, respectively, would suggest that clean groundwater is flowing into the Oxbow Lake, which is clearly not true. The only control to the east of the plume centerline is one location, which is more than 2,000 feet away. However, the isoconcentration lines are drawn in tightly on that side of the plume, indicating confidence in concentration locations. Figure 12 indicates that uranium concentrations in the surficial aquifer fall off much more steeply on the east side of the plume than on the west side. With data points so far apart, DOE's interpretation of the extent of contamination is not credible.

The DOE states:

> *"The data indicate that the surficial aquifer is discharging contaminated groundwater into the Oxbow Lake, and that concentrations of the COPCs are decreasing over time in the Oxbow Lake. This may indicate that the original pulse of site-related contaminants has already been discharged to the Oxbow Lake and the Little Wind River."* (DOE, SOWP, 1998a).

However, the data presented do not support this interpretation. The effects of evaporation and dilution have not been considered in their interpretation of the data. All standing surface water bodies are subject to the effects of evaporation and dilution, making the concentrations of contaminants in a water sample primarily a function of whether the sample was taken in a period of dry or wet weather. The interpretation that COPCs are decreasing over time in the Oxbow Lake is based on concentrations of uranium (for example) that were measured at 0.647 mg/L in 1995 and 0.217 mg/L in 1997. If the concentration of a conservative constituent like chloride (one that does not participate in most chemical reactions) is used as a measure of any evaporation or dilution, we note that the chloride concentration in 1995 was 100 mg/L and 27 mg/L in 1997. A calculation ($100 \div 27 = 3.7$) reveals that the concentration of water in the Oxbow Lake was 3.7 times more dilute in 1997 than in 1995. This difference may be due, for example, to a recent rainstorm in the area. If we normalize the uranium concentration in 1997 to chloride (3.7×0.217 mg/L = 0.80 mg/L) to reduce the effects of dilution, the uranium concentration in 1997 is probably actually higher than the concentration measured in 1995. A conceptual model that does not take evaporation and dilution into account when drawing conclusions for surface water could have dangerous consequences for people exposed to surface water because evaporation has the potential to increase concentrations of contaminants to very high levels. Accurate conclusions on contaminant concentration trends in surface water cannot be made without taking into account the effects of evaporation and dilution.

DOE believes that the Oxbow Lake will eventually fill in with sediment and will thus no longer be a human health risk (DOE, EA, 1998b). Geomorphological and sedimentological research indicates that the lake may fill eventually. However, it is the length of time before the lake fills with sediment that is in question. According to Bloom (1978), the general process of Oxbow Lake development is as follows:

> *"Sometimes erosion is sufficient to begin an entirely new master channel, and a segment of the former channel is abandoned, to slowly fill with channel deposits and peat along a curved Oxbow Lake."*

The key phrase in this reference may be the term "slowly."

Reineck and Singh (1980) describe the process as follows:

> *"The abandoned channels are slowly alluviated and sealed at both ends, isolating the old channel loop in the form of a cut-off lake, or ox-bow lake. In the beginning, sedimentation is rather rapid at and near the ends of the cut-off lakes. However, later the rate of sedimentation in the cut-off lakes is very slow. Some suspended material is introduced during overbank flows. Mainly clayey sediments and organic matter are deposited until filling is complete."*

Again, the lake-filling sedimentation process is characterized as "very slow". To further support the slow rate of sedimentation, Reineck and Singh refer to the presence of floral and faunal communities in the lake:

> *"Most of the cut-off channels become lakes with abundant fauna and flora. Pockets of freshwater mollusks and plant remains may become incorporated within the sediment. Otherwise, muddy sediments are very thinly laminated."*

The referenced literature suggests that the ends of the ox-bow lake may fill quickly with sediment, but that the remainder of the lake only fills slowly and with fine-grained sediment such as clay and silt. These types of sediment are transported by very low-velocity, overbank flow during seasonal flood events, and the floodwaters may be weeks in receding back into the main river channel. Sediment deposition under these processes occurs by vertical accretion (Bloom, 1978). The fact that flora and fauna (e.g., fresh water mollusks) are common in ox-bow lakes is an indication of the low sedimentation rate within the ox-bow lake environment. Higher sedimentary rates cover and kill fresh water mollusks. The rate of sediment filling in the Riverton ox-bow lake depends on the magnitude of seasonal flooding and the quantity of suspended sediment load in the overbank flow. An understanding of these processes suggests that the life of the ox-bow lake could, in fact, be longer than the projected 100-year life of the natural flushing scenario. Within such a period of time, the risk of human exposure to the ox-bow lake could be significant.

3.3.3 Sediment and Vegetation

An extensive discussion comparing background levels of COPC with levels observed in potentially impacted sediments and vegetation has been presented, but the details of sampling methods or procedures are not provided. In general, it appears that only one or two samples of each type were collected from each sampling location. It is very difficult to adequately characterize sediment and vegetation in the area with such a small number of samples. The amount of variation in sediment can be significant, and this variation should not be assessed with such a small sample population. One problem with sediment sampling is that a major factor affecting the measured constituent concentrations is the grain size of the sample. This factor can cause large differences in analytical results even at the same location. For example, clay and silt have a much higher cation exchange capacity than sand, causing more constituents to adsorb onto clays and silts than onto sand. DOE has measured the cation exchange capacity of samples, but these results very widely within the sample set (e.g., from 10 to 70 mill equivalent per kilogram [meq/Kg]), indicating a wide variation in sediment type. Given that there can be a large variation in sediment type within a few feet at any location, a comparison of the results from a sample collected in one location to a sample collected at any other location is not reliable, unless samples have a similar grain size distribution. Differences in contaminant concentrations in samples may be due more to differences in sediment type rather than any real differences in total contamination of the particular location. There is insufficient information presented to make predictions concerning contamination or lack of contamination with respect to background in sediment and vegetation.

3.3.4 Effects of Changes in pH

The DOE EA (1998b) states the following:

> *"After further evaluation of data, including results of the most recent (1997) round of sampling (DOE 1998a, Appendix B2), arsenic was eliminated as a constituent of potential concern because concentrations have decreased through time and are currently within the historical range of background values."*

This conclusion potentially puts the population downgradient of the Riverton site at risk. Rai and Zachara (1984) note that while arsenic adsorption is high and independent of pH at low pH, adsorption decreases with increasing pH. To quote:

> *"Arsenic adsorption on amorphous and crystalline hydrous oxides* [ferric oxyhydroxides] *and layer lattice silicates exhibits marked pH dependency and suggests high mobility of arsenic under alkaline conditions."* (Rai and Zachara, 1984).

DOE SOWP (1998a) states:

> *"...the main attenuation mechanism for arsenic removal is probably adsorption onto aquifer materials, particularly ferric oxyhydroxides".*

The original tailings fluids from the acid circuits at this site were strongly acidic (i.e., very low pH). As water moves through the subsurface in the area of the original tailings pile, it slowly neutralizes the acidic conditions. As conditions become more neutral, there is a potential for an arsenic "bloom" in the groundwater. Arsenic that had been adsorbed to soil under the low pH acidic conditions will likely desorb and enter groundwater. Arsenic concentrations in groundwater may rise if this occurs. Since arsenic concentrations in groundwater could certainly increase due to pH changes, arsenic should have been retained as a COPC.

Arsenic is not the only contaminant in the Riverton site groundwater whose ultimate fate and transport is dependent on adsorption/desorption reactions controlled by groundwater pH. In the low pH, near-site groundwater, molybdenum is likely present in solutions as MoO_2^+, a cation (Brookins, 1988). The adsorption sites on ferric oxyhydroxides are strongly positive at low pH and do not adsorb cations. Therefore, MoO_2^+ would be expected to be highly mobile and may account for the observed early rapid movement of molybdenum though the aquifer. However, at pH values greater than about 4.3, MoO_4^{2-}, an anion, becomes the dominant molybdenum species in groundwater (Rai and Zachara, 1984). While ferric oxyhydroxides adsorption sites become increasingly more negative as the pH of the solution increases, the zero point of charge (negative sites exactly balanced by positive sites) is not reached for most of these minerals until the solution is significantly alkaline (pH of 7 to 9) (Langmuir, 1997). Therefore, transport of molybdenum in groundwater may slow as adsorption becomes more effective. Section 3.4 of this report, providing a review of the contaminant transport model, notes that the most important parameters in controlling flushing time are far field hydraulic conductivity and distribution coefficient. The above discussion indicates that the distribution coefficient (a constant that tries to account for how much of a constituent is adsorbed on the aquifer matrix and how much remains in solution) for molybdenum would likely be considerably different for early periods in the systems history than in later periods. This difference could lead to much longer flushing times than are predicted in the contaminant transport model. The contaminant transport model fails to account for the variation expected over time in the distribution coefficient.

3.4 Groundwater Model Analysis

3.4.1 Computer Code Description

The DOE used the GANDT code to simulate subsurface contaminant movement and provide information to support a groundwater corrective action. The GANDT code is designed to analyze flow and transport of contaminants from a source area in the unsaturated zone, through the unsaturated soils underlying the source material, and subsequently into and within the saturated zone (DOE, SOWP, 1998a). The code uses a linear adsorption model to account for retardation/attenuation of chemical parameters. GANDT attempts to account for uncertainty through probabilistic simulations based on the Monte Carlo method in conjunction with Latin Hypercube Sampling (LHS) of stochastic model parameters. Probabilistic results from the code attempt to provide estimates of the likelihood of occurrence of specific transport scenarios.

GANDT is designed to simulate subsurface contaminant movement using screening level, analytical solutions of advective-dispersive transport. A numerical, three-dimensional, finite-difference groundwater flow and transport solution based on the public-domain code FTWORK (Faust et al., 1994) was used for the Riverton study because this package allows for groundwater discharge to a river. Geostatistical conditional simulation (Peck et al., 1989) was used in an attempt to account for spatial variability of hydraulic conductivity, algorithms for which are taken from the GSLIB system of codes (Deutsch and Journel, 1992). GANDT is described as having the ability to automatically condition model runs on observed water quality data (DOE, SOWP, 1998a). This feature is described as the primary technique for model calibration. The code employs an automatic grid generator for ease of use in setting up a finite-difference grid when employing FTWORK. Data input and the examination of results from probabilistic analyses are accomplished through a proprietary user interface.

3.4.2 Sources of Error

The modeling analysis used by the DOE in support of its selection of natural flushing for correcting groundwater contamination at the Riverton site is more sophisticated than is typically performed outside of the nuclear repository siting arena. However, in light of the deficient database, it is unclear whether the complexity and sophistication of this model increases the accuracy of the predictions made by the model and supports natural flushing as a viable remediation alternative. This section addresses the philosophical issues revolving around uncertainty and why this type of modeling analysis has been performed.

A model is only a representation of reality. Therefore, models will always have some ambiguity or uncertainty associated with them because all the parameters, processes, and hydrologic conditions that occur in reality are not exhaustively known. Assumptions must be made. The effects of uncertainty are manifested in a model's inability to make an accurate, or even reasonable, prediction. Studies (called post audits) of model predictions after the fact have revealed that models have not had good success as predictive tools. Generally, these modeling studies have not recognized uncertainty or attempted to address it in any way.

The following three sources of model error leading to uncertainty are taken from Konikow and Bredehoeft (1992):

1. Conceptual Errors. The understanding of the basic processes that are operating at the site. (Note: at Riverton, a potential conceptual error is in the assumption that the linear adsorption model is a valid description of uranium interaction with the aquifer matrix.)

2. Numerical Errors. Errors from the computational algorithms such as truncation and round off.

3. Parameter Errors. Uncertainty and inadequacy of the data used to describe aquifer properties and boundary conditions. For instance, if the linear adsorption conceptual model of uranium geochemistry is correct, what is the value of the partition coefficient that should be used? Is it the same everywhere?

This review focuses its attention on conceptual and parameter errors.

Carrera (1993) discusses uncertainties in groundwater solute transport modeling. He concludes that heterogeneity is the major source of uncertainty in transport modeling, at least in terms of gross behavior, and is described as a parameter rather than a conceptual uncertainty. He states that the stochastic or probabilistic (also called Monte Carlo) representation of aquifer hydraulic conductivity results in a closer approximation of reality than many other methods. In this context the DOE modeling analysis has more credibility than a deterministic approach. However, as discussed in the following sections, there are more subtle issues that affect credibility involved.

The framework of stochastic or probabilistic analysis is used to address the role of natural variability and its influence on uncertainty. In this approach, the parameter uncertainty is represented in terms of random flow and transport parameters characterized by a limited number of statistical parameters. These random parameters are then input to the classical equations that describe groundwater flow, essentially repeating the modeling process many times. The resulting suite of predictions is then represented by probability distributions or in terms of statistical moments (i.e., mean and variance). This is the approach taken by the DOE in assessing the viability of natural flushing and is advocated by Konikow and Bredehoeft (1992) as one way to bound predictions.

In contrast to the stochastic approach described above, the deterministic approach attempts to determine, as best as possible, the true parameters of the aquifer. While this approach does have its strengths (Carrera, 1993), it is subject to uncertainty due to compensating errors in establishing the parameters.

In principle, by repeating the flow and transport model analysis of the site many times using different parameters and requiring that each iteration match the data to a certain degree, the uncertainty in model prediction is captured. If the model is a reasonable representation of reality, the model-estimated uncertainty could be related to reality. Interpretation of probabilistic modeling results should be made within the context of the following statement:

> *Given the assumptions in the numerical model (e.g., Little Wind River is a gaining stream, K_d approach valid throughout domain, etc.) and the supposition that they are representative of reality the chance that contamination will exceed MCL is given by the GANDT model probability of exceedance maps. The more these assumptions deviate from reality the less the GANDT probabilities have any relation to reality.* (DOE, SOWP, 1998a)

3.4.3 Probabilistic Approach

The use of a probabilistic approach still does not guarantee that the model has any relation to reality. Konikow and Bredehoeft (1992) and Oreskes et al. (1994) discuss the issue of model validation or substantiation of model predictive power that holds for both deterministic and probabilistic approaches. They present key points as follows:

- Model predictive value is always open to question (Oreskes, et al., 1994).
- Scientific judgment needs to be a component, outside of model analysis, in judging that the proposed actions are reasonable (Konikow and Bredehoeft, 1992).

The only way to tell if the model results are reasonable is to test its predictions versus reality and realize that even then, at any time over the next 100 years, the model prediction may fail.

A mathematical model such as that used by the DOE at Riverton is a representation of reality. The difficulty comes in understanding and interpreting reality using often sparse and contradictory data, and then translating it into an equivalent mathematical representation. The single most important tool for doing this is the *conceptual model*, as defined below (ASTM, 1993):

> <u>Conceptual Model</u> – *an interpretation or working description of the characteristics and dynamics of the physical system. The purpose of the conceptual model is to consolidate site and regional hydrogeologic data into a set of assumptions and concepts that can be evaluated quantitatively. Development of the conceptual model requires the collection and analysis of hydrogeologic and hydrologic data pertinent to the aquifer system under investigation.*

Bear et al. (1992) make the following observation about the conceptual model:

> *". . . the importance of the conceptual model cannot be overemphasized. It is possible that the existing data will indicate more than one alternative model, if the available data (or lack of it) so dictates.*

If the conceptual model developed for a site is wrong, the parameters used in the model will not represent any aspect of the physical system, and calibration simply becomes an exercise in model fitting unrelated to reality. Therefore, a critical point is that if the conceptual model is wrong, then the numerical model will be meaningless. The first and most important question that must be answered is whether the conceptual model is valid and supported by the data. If the answer is that that the conceptual model is valid, the second question is, has the conceptual model been properly implemented in the numerical model? The first question is addressed in Sections 3.2 and 3.3.

The DOE (EA, 1998b) clearly recognizes that the available data are ambiguous. They state on page 19 of Appendix D, the modeling report, that

> *"The assumption that the Little Wind River downgradient of the site is a gaining stream may be questioned due to lack of conclusive evidence demonstrating such a phenomenon."*

The GANDT model appears to represent the conceptual model developed in DOE (SOWP, 1998a). However, the accuracy of the site conceptual model is in question because.

High-sulfate concentrations have been detected at Well 735 on the other side of the Little Wind River, casting doubt on the assumption that the surficial and semi-confined aquifers discharge completely to the river.

3.4.4 Functionality of DOE's Proprietary Code

GANDT has not been widely used outside (or inside) of DOE UMTRA. Thus, its track record and proprietary nature has the potential to make it somewhat controversial. Mercer (1987) briefly discussed the issues surrounding proprietary codes, and his points along with our comments are as follows:

- *Use of proprietary codes encourages code development for solving new problems.*

GANDT does not solve a new problem. The literature is full of applications where public domain flow and transport codes have been used to do Monte Carlo or probabilistic analysis. GANDT adapted its numerical transport code from FTWORK, a proven code from knowledgeable and experienced developers. Proper implementation within GANDT is unknown. The same issue surrounds the GSLIB geostatistical simulator, which was adapted for GANDT.

- *Use of proprietary codes encourages developers to make codes user-friendly and to provide appropriate documentation.*

GANDT clearly has many features that make it user friendly. However, so do other non-proprietary software that can be used for at least part of this problem (see next point).

- *Proprietary codes provide solutions to some problems that publicly available codes cannot solve.*

This is not applicable to this site. At least part of the GANDT functionality is replicated in the commercially available Groundwater *Vistas* software. In addition, parameter samples could be generated externally to the model using a tool such as *Crystal Ball* and data sets prepared using the samples.

- *Proprietary codes generally undergo a rigorous QA/QC* [quality assurance/quality control] *program.*

Whether this is true of GANDT is unknown.

- *User support is available for proprietary codes.*

This point appears to be moot since GANDT is not distributed.

The GANDT reference manual was obtained and reviewed and does not contain any substantial documentation of code verification. However, there is at present no reason to believe that Sandia National Laboratories, renowned for its technical expertise, would have produced a code with major flaws that would render its results meaningless.

Parameter distributions for Monte Carlo analysis are typically developed (Nichols and Freshley, 1993) by fitting to observed data (e.g., porosity). However, in the case of the Riverton site, not enough data for any parameter were available for rigorous analysis and, therefore, assumptions were made for the distributions. The choice of distribution can have an impact on the results. In the absence of extensive data, the distribution needs to be carefully considered. Woodbury et al. (1995) investigated the effects of assuming the distribution in stochastic analysis. They used uniform and Gaussian distributions to analyze outcomes of draw down from a pumping well. The results from using the uniform distribution had an uncertainty with considerably more spread than the results when a Gaussian function was used for parameter sampling. This is because the Gaussian distribution will draw more values near the mean than from the extremes of the distribution. They point out that it is possible to obtain bounding estimates of parameters that are used directly in a uniform distribution, but it may be difficult to obtain enough data to assign a site-specific distribution for any other distribution. This is very true of the Riverton site, which has a poor database. Thus, it may be possible that the analysis is biased by the choice of parameter statistical distribution.

Most of the distributions used in the GANDT analysis for this site were uniform, which implies the least amount of knowledge about the statistical distribution of uncertainty and results in the greatest amount of potential spread in the simulated outcomes. This is a reasonable approach, although the source of the bounds is not clear. Log normality was assumed for saturated hydraulic conductivity, and normality was assumed for initial soil concentrations, porosity, residual water content, and the van Genuchten parameters. A combination of general literature and trial runs are cited for ~~the~~ last list, but no specific reference is provided to evaluate the reasonableness of the assumed distribution.

Probably the most important parameters in controlling flushing time are far field hydraulic conductivity and distribution coefficient. In this case, hydraulic conductivity was assumed to have a univariate log normal distribution and to be spatially correlated. This assumption has a long and controversial history in hydrogeology and could have an impact in the modeling analysis. In contrast with DOE's assertion that hydraulic conductivity is typically log normally distributed, de Marsily et al. (1998) point out that "*it is well known that hydraulic conductivity may display non-Gaussian distributions*". Thus, while data scarcity may have dictated that the operational decision had to be made to assume log normality for the hydraulic conductivity distribution, reality might be quite different. A further consequence of assuming log normality was reflected in the choice of the Sequential Gaussian Simulation method to generate the random fields. This method introduces maximum disorder (Journel and Alabert, 1989), which is typically not a characteristic of geologic materials.

Analysis with an accepted method (the semi-variogram) and code (Variowin) established the spatial correlation of hydraulic conductivity. The 13 pumping test data points shown in Figure 13 produce $n(n-1)/2$ number of pairs (Isaaks and Srivastava, 1989) for a total of 78 pairs. Journal and Huijbrects (1978) suggest that about 30 pairs should report to each semi-variogram; thus the pumping and slug test data would provide enough lags for a reasonable experimental semi-variogram analysis. The four points used by DOE are reasonable. However, the experimental semi-variogram is fitted with an analytical model, and the data shown in Figure 14 do not appear to conform well to the model chosen by DOE. While an exponential model would fit the data much better (Figure 14), the differences might be insignificant with only four points. Still, there is an important difference between the two that might have an impact on flushing time. The correlation scale of the DOE semi-variogram is 1,200 feet and that of the review team is 6,000 feet. The two cannot be directly compared because of the difference in the correlation die off function, but the effective range of the exponential model, which can be compared to the spherical model, is one-third of the total range or 2,000 feet. The effective range of the exponential model is 67 percent greater relative to the DOE model, which implies that the distance of influence of a data point on the hydraulic conductivity field is greater. Once beyond the range of data points, the simulated value tends to fluctuate around the mean (the geometric mean in this case since the simulation is in log space). A longer semi-variogram range creates larger low hydraulic conductivity areas, which are more slowly flushed. Because the semi-variogram is dependent on the data and is only an estimate of the "true" correlation structure, it will always be subject to uncertainty. However, the available data should have been fitted with a better semi-variogram model.

A larger problem with the semi-variogram than the poor fit shown in Figure 14 is that the parameters reported in the text do not replicate the curve shown in the figure. The semi-variogram appears to have the following parameters: a nugget of 0.24 log (feet per day [ft/d]), range of 1,200 feet, and a sill of 0.293 $[\log (\text{ft/d})]^2$ (Figure 14). DOE combined slug and pumping test values in generating the hydraulic conductivity field for the flow model, which is desirable because additional constraint is added but is also problematic because it can be difficult to ascertain the representativeness of the results. Butler (1998) advocates that slug tests should generally be considered lower bound estimates of aquifer properties, which would tend to slow flushing and produce worst-case estimates of flushing time.

While the use of geostatistical simulation to more properly deal with heterogeneity is commendable, the technique tends to neglect, or cause the analyst to neglect, the geological reasons for the heterogeneity. In the SGS code, hydraulic conductivity is simply a random variable that varies between low and high values. In reality, the higher values are associated with sandier parts of the alluvial depositional cycle, and the lower values are associated with more clay parts. The depositional process is not random, merely very complex. Davis et al. (1993) point out that the finer grained aquifer materials often have higher partition coefficients for a variety of reasons, and that there is a negative correlation between hydraulic conductivity and adsorption. Thus, the higher hydraulic conductivity areas will have a lower K_d and the converse. GANDT assumed a single K_d for the entire model. This assumption probably lead to an understatement of K_d variability since adsorption was then assumed to occur uniformly over both low and high hydraulic conductivity parts of the aquifer. Thus, the model may have overstated the degree to which flushing reduces concentrations in the low hydraulic conductivity part of the aquifer, which is the controlling factor in long-term cleanup.

As discussed in the modeling report mechanical dispersion of contaminants occurs because of local velocity variations caused by heterogeneity. The mixing effect has been postulated to be a function of plume travel distance, often held to be approximately one-tenth of the travel distance (Zheng and Bennet, 1995). This rule was derived from simple numerical model and analytic method analysis, where heterogeneity was largely neglected and all spreading is attributed to dispersivity. If sufficient heterogeneity were provided, no dispersivity would be required since the velocity variations would be accounted for explicitly by the flow field (Gelhar, 1986). It is approximately 2,000 feet from the corner and 4,000 feet from the center of the site to the hypothesized discharge point at the Little Wind River. Using the one-tenth rule of thumb suggests longitudinal dispersivity ranging from 200 to 400 feet. In a model such as that developed for Riverton, the dispersivity should be lower than those specified as input because there is much more detailed representation of the heterogeneity. By using larger dispersivity, the dilution of the plume will occur more quickly than otherwise and may be biasing the results.

DOE rightly recognizes that geochemical conditions during milling operations and the early development of groundwater contamination were likely different than those today. Conditions during the early formation of the plume would have enhanced uranium migration.

Because the model is unable to compensate for this, GANDT model parameters must allow faster uranium migration during the calibration phase that would result in a prediction of faster flushing. A deterministic model that allows spatially varying adsorption can more accurately address these conditions.

3.4.5 *Analysis of Report Documentation*

EPA has released a guidance document for Monte Carlo analysis (EPA, 1997) that discusses the relevant issues and presents guiding principles for probabilistic approaches to risk assessment. While the target application is human health and ecological risk assessment, the formulation is general enough to be useful for our purposes. The conditions for an acceptable risk assessment that uses probabilistic techniques are excerpted as follows:

1. The purpose and scope of the assessment should be clearly articulated in a "problem formulation" section. The questions the assessment attempts to answer are to be discussed and the assessment endpoints are to be well defined.

2. The methods used for the analysis (including all models used, all data upon which the assessment is based, and all assumptions that have a significant impact upon the results) are to be documented and easily located in the report. Sufficient information is to be provided to allow the results of the analysis to be independently reproduced.

3. The results of sensitivity analyses are to be presented and discussed in the report. Probabilistic techniques should be applied to the compounds, pathways, and factors of importance to the assessment, as determined by sensitivity analyses or other basic requirements of the assessment.

4. The presence or absence of moderate to strong correlation or dependencies between the input variables is to be discussed and accounted for in the analysis along with the effects these have on the output distribution.

5. Information for each input and output distribution is to be provided in the report. This includes tabular and graphical representations of the distributions (e.g., probability density function and cumulative distribution function plots) that indicate the location of any point estimates of interest (e.g., mean, median, 95th percentile). The selection of distributions is to be explained and justified.

6. The numerical stability of the central tendency and the higher end (i.e., tails) of the output distributions are to be presented and discussed.

7. Calculations of exposures and risks using deterministic (e.g., point estimate) methods are to be reported, if possible. Providing these values will allow comparisons between the probabilistic analysis and past or screening level risk assessments. When comparisons are made, it is important to explain the similarities and differences in the underlying data, assumptions, and models.

In general, the above formulation largely meets the requirements for a groundwater modeling uncertainty analysis. Items 1, 2 and 3 are considered part of any well-documented modeling report (see, for instance, Anderson and Woessner, 1992). Item 4 also should be considered, Item 5 should be included, and Item 6 would be desirable. Rather than exposures as mentioned in Item 7, concentrations could be used, but no deterministic model was developed for the site and these data are not available. The report generally meets these requirements.

The DOE (SOWP, 1998a) indicates that the methodology used in GANDT requires no sensitivity analysis. However, they fail to recognize that there may be uncertainty about their uncertainty. EPA (1997) identifies this issue by stating the following:

> *"When data for an important parameter are limited, it may be useful to define plausible alternative scenarios to incorporate some information on the impact of that variable in the overall assessment. In doing this, the risk assessor should select the widest distributional family consistent with the state of knowledge and should, for important parameters, test the sensitivity of the findings and conclusions to changes in distributional shape."*

DOE failed to perform this type of sensitivity analysis with GANDT.

The key test of any model is if the model prediction matches reality. The hydraulic head matches shown in the report appear quite reasonable, and there is no basis to reject the model on these results. A more important test is comparing the predicted groundwater concentrations to reality; that is, what concentrations have been measured. The 1999, 2000, and 2001 sampling results for uranium were used, along with the previous samples and the estimated (since only graphical output was provided) concentrations for key Monitor Wells 707, 722, and 716. Figures 15 and 16 show the results of this limited test for Monitor Wells 722 and 707, respectively.

As shown in Figure 15, the data and the predictions are in good agreement in magnitude and trend at Monitor Well 722. This is important since Well 722 is the upgradient edge of the plume wh~~ere~~ deviations from the projected flushing behavior will be manifested first. The results for Monitor Well 707 are shown in Figure 16. The agreement with magnitude and trend is not as good as that seen at Monitor Well 722. This lack of agreement is probably due to insufficient plume characterization.

In summary, the model, to the degree to which it represents hydrogeologic reality, does suggest that natural flushing may reduce uranium and molybdenum concentrations in groundwater below the MCL in the next 100 years. However, based on the previous discussions, GANDT's predictions are unreliable because:

- Site-specific data to support the conceptual model (upon which the stochastic model is based) are sparse, making it difficult to determine if modeling accurately represents reality.
- The available data indicate that at least one key assumption in the conceptual model, that the surficial aquifer always discharges to the Little Wind River, is suspect.
- The GANDT Model does not account for time-varying geochemical conditions or spatially varying adsorption.

3.5 Risk Assessment

3.5.1 Background Concentrations

There are several instances in the BLRA where conclusions are drawn and based on insufficient data. If the data are not representative of true exposure point concentrations, then the estimates of risk based on the exposure point concentrations are likely not valid. For example, only one round of groundwater data was available for identifying background groundwater quality in the semi-confined aquifer. The identification of background quality is significant in the risk assessment because one of the screening mechanisms used in the identification of COPC is a comparison of site-related contamination concentrations to background concentrations. If the site-related concentrations do not exceed background, that constituent is eliminated as a COPC. If the one background sample is not actually representative of background, constituents that should be included as COPC and evaluated further could be eliminated and constituents that should not be included as COPC may be included.

For sediment, only one upstream sample (considered characteristic of background sediment quality) was collected and very few downstream sediment samples were collected in the Little Wind River and the other wetland areas. It is difficult to adequately characterize an area based on such a small sample population, specifically for sediment because physical characteristics in sediment can significantly affect the contaminant concentrations. DOE failed to consider the following factors:

- Sediment grain size, location (depositional area versus scoured area), and depth of sample

- Like samples for the comparison of the background versus site-related samples

- Statistically significant data sets to identify representative background concentrations as well as representative site-related concentrations

3.5.2 Use of Domestic Wells

It is unclear if, in fact, people are drinking impacted water from the semi-confined aquifer. Table 1 of the BLRA (DOE, BLRA, 1995) lists the private wells in the area, and two wells are identified as screened in the semi-confined aquifer. These wells are identified as used for stock watering only. However, it is not known if adequate controls are set in place that prevent domestic use of water from these wells in the semi-confined aquifer. The BLRA only assessed risks associated with drinking water from the uppermost, unconfined aquifer, not the semi-confined aquifer. In evaluating the potential for risks to people in this area, it is important to understand the following:

- Are the concentrations identified as representative of groundwater quality in the semi-confined aquifer accurate or are they based on insufficient data?

- Are people drinking water from the semi-confined aquifer even though the wells completed in this unit are identified as used solely for stock watering? The BLRA acknowledges that people in the area have become used to the poor quality water and some even find it palatable. There could be a significant risk associated with this exposure. Section 6 of the BLRA (DOE, BLRA, 1995) states that concentrations of manganese, molybdenum, sulfate, and uranium reported in groundwater from the semi-confined aquifer would cause problems if ingested on a chronic basis.

- Is the semi-confined aquifer hydraulically connected to and adversely affecting the confined sandstone that provides drinking water to many residents in the area?

All of these affect the accurate prediction of risks associated with groundwater ingestion.

3.5.3 Other Exposure Pathways

The BLRA quantitatively assesses only groundwater ingestion. Other possibly complete exposure pathways are "screened" and eliminated as insignificant in comparison to ingestion of groundwater. The possibly complete exposure pathways that were screened in the BLRA include dermal absorption of constituents, ingestion of groundwater irrigated produce, ingestion of meat from groundwater-fed livestock, ingestion of milk from groundwater-fed livestock, ingestion of surface water while swimming, ingestion of fish from the Little Wind River, and ingestion of sediment during recreation. Volatilization of contaminants from the groundwater, often addressed in risk assessments, is not evaluated because the COPC are inorganic and do not volatilize. The Arapahoe Community Water System (see Section 3.6) for a discussion of the "alternate water supply") is in contact with the contaminated groundwater plume. A properly designed, installed and maintained public water supply system should be able to withstand the COPC in groundwater. However, DOE apparently neither investigated the integrity of the system nor considered it as a potential exposure pathway.

There is a cumulative risk if people are exposed to groundwater or affected media through other exposure pathways (e.g., ingestion of produce irrigated with impacted groundwater, ingestion of meat and/or milk from groundwater-fed livestock, ingestion of surface water while swimming, ingestion of fish from the Little Wind River, and ingestion of sediment while recreating). The risk associated with ingestion of contaminants in groundwater may be the most significant contribution, but a BLRA typically evaluates risks associated with all complete exposure pathways and then sums the risks for a particular receptor if that receptor can be exposed through several exposure pathways. The cumulative risks may be significant, especially if people are not drinking the water. The risks for people not drinking impacted water would then be solely through the other potentially complete exposure pathways. If affected groundwater discharges to Little Wind River, then potential risks associated with exposure to sediment and surface water (although sediment would be the primary affected media as the COPC tend to sorb to sediment rather than stay suspended in surface water) in Little Wind River and the oxbow could be important. Because the cumulative risks to people exposed through the screened out exposure pathways could be significant, DOE should have quantified the risks for all complete exposure pathways using valid exposure point concentrations based on statistically significant data sets.

Generic exposure assumptions were used in the screening of exposure pathways. It does not appear that cultural differences have been incorporated. While the specific range of exposure assumptions used in the quantification of risks was not presented in the document, it is likely they were similar to that used in the screening exercise. One example of a generic assumption is the fish ingestion rate of 0.054 kilograms per day used in Table 2 of the BLRA (DOE, BLRA, 1995). This assumption likely underestimates fish ingestion for a population containing members that practice subsistence fishing.

3.5.4 Synergistic and Antagonistic Effects

The toxicity assessment presented in the BLRA is quite comprehensive but appears to be very generic. It does not appear that possible synergistic and antagonistic effects that might result from interactions between the specific COPC at this site were considered. For example, could there be more significant or pronounced health effects if a person is exposed to both elevated sulfate and molybdenum in drinking water? Furthermore DOE failed to address the potential interactions of the COPC to determine whether effects could be more pronounced if people are exposed to COPC in combination and/or if Native Americans are more susceptible to the adverse effects of a specific COPC. Section 5.1.1 of the BLRA (DOE, BLRA, 1995) states that genetic dispositions may decrease the methylation of arsenic and result in the increased deposition of arsenic in the lungs or skin. Do Native Americans possess a genetic disposition for this or other contaminants? For example, research indicates that a number of chemicals adversely affect liver function. It is possible that exposure to one contaminant may not be significant in terms of adverse health effects but exposure to several contaminants that exert toxic effects on the same organ may result in toxicity. The data presented in the BLRA indicate that the BLRA does not address this potential for synergistic effects. Because the cumulative risks to people exposed through the screened out exposure pathways could be significant, DOE should have quantified the risks for all complete exposure pathways using valid exposure point concentrations based on statistically significant data sets.

3.5.5 Livestock and Ecological Impacts

The Livestock and Environmental Evaluation is a screening assessment only. Very little data were collected to assess ecological impacts. As mentioned earlier, there were insufficient sediment data available for the Little Wind River, wetland areas, and Oxbow Lake. Additional data, specifically sediment data, would have been required to more accurately assess the potential for ecological impacts.

Section 7.5 of the BLRA (DOE, BLRA, 1995) states that use of groundwater from Monitor Well 707 for livestock watering may cause adverse effects. The text states that that conclusion is based on comparing concentrations of only 11 of the 21 COPCs in groundwater to comparison values considered protective of livestock. The text goes on to state that effects associated with the other constituents cannot be evaluated because there is not sufficient information to make a comparison. Monitor Well 707 is in the surficial aquifer. Using contaminant concentrations from wells completed in the semi-confined aquifer would have provided a better estimate of actual risks to livestock, as there are two wells completed in this unit that are reportedly used for stock watering.

3.6 Regulatory Issues

This section discusses some of the key regulatory issues that have influenced and should continue to influence the regulatory status of the Riverton Site. The most significant issues requiring comment concern the application of institutional controls during the Long Term Surveillance and Maintenance phase. Therefore, this Section will be structured as follows:

- A brief summary of NRC obligations under the Uranium Mill Tailings Radiation Control Act (UMTRCA) is provided.
- A summary of the current regulatory status of the Riverton Site.
- A discussion on institutional controls and their role in the EPA's groundwater regulations for the UMTRA Groundwater Program.
- A discussion of relevant information on the Long-Term Surveillance and Monitoring (LTSM) Program.
- A discussion of the interrelationship between institutional controls and the LTSM Program, comments are presented on the efficacy of institutional controls and possible long-term monitoring issues.
- Comments on the applicability of monitored natural attenuation to the Riverton Site and DOE compliance with EPA regulations.

3.6.1 Summary of NRC Obligations Under UMTRCA

Congress passed the UMTRCA (Public Law 95-604) in 1978 to address the issue of contamination associated with uranium mill tailings sites. The law required EPA to promulgate standards related to the disposal and cleanup of mill tailings. EPA 40 CFR 192 (Federal Register, January 11, 1995) presents the final groundwater regulations for the UMTRA groundwater program. The NRC is designated by the UMTRCA as the federal regulatory oversight agency for the UMTRA Project. As part of this oversight responsibility, in 1980 the NRC published the Final Generic Environmental Impact Statement on Uranium Milling (NRC, 1980). This document assessed the nature and extent of the impacts of uranium milling and provided information on the regulatory-requirements for management and disposal of mill tailings and mill decommissioning. This generic environmental impact statement is the programmatic environmental impact statement for the UMTRA Surface Project including the Riverton site. Remedial actions are selected and performed with the concurrence of the NRC.

The DOE and its subcontractors evaluate the data and propose a specific course of action in a document (see Section 3.6.2). The DOE then submits information on their proposed course of action to the NRC for review. The NRC must complete a technical and regulatory review of the DOE's information and make recommendations. The DOE then develops a detailed plan to implement the course of action and submits that plan to the NRC for another technical and regulatory review. If NRC concurs, the DOE implements the plan. If NRC does not accept the DOE's plan, the plan is reworked until it is acceptable to the NRC and the work is initiated. Following NRC concurrence the DOE remediates the specific inactive mill site. The NRC's concurrence with each component of the site's course of action is required to obtain a license for the disposal sites; the NRC licenses the completed disposal sites for long-term care.

3.6.2 Regulatory Status of the Riverton Site

The regulatory process required to be completed by the DOE to fulfill their obligations for the Groundwater Program under the UMTRCA is illustrated in Figure 17 (taken from the UMTRA Groundwater Project, Project Information Web Site: http://www.gjo.doe.gov/ugw/general/pro-info/pro-info.htm). This process starts with the BLRA, issued in 1995 for the Riverton site, to determine if groundwater at the site poses an immediate risk to human health and the environment.

Next is preparation of the SOWP, issued in 1998 for the Riverton Site, to characterize site groundwater conditions and document DOE compliance with EPA standards. The Draft GCAP, issued in 1998 for the Riverton Site, proposes the groundwater compliance strategy to be used at the site so that various NEPA documentation can be prepared. The EA, issued in 1998 for the Riverton Site, analyzes the effects of the proposed groundwater compliance strategy as well as a no further action scenario. If implementation of the proposed compliance strategy would result in no significant impact to the environment, a FONSI is issued. The Riverton FONSI consists of a one page public statement of the findings of the EA, and was issued in September 1998. NEPA also requires a Public Involvement Plan, issued in 1998 for the Riverton Site. The Final GCAP is issued following the NEPA process allowing remedial action to begin. Maxim has been unable to verify that a Final GCAP has been issued for the Riverton Site. Verification monitoring is implemented for passive remediation sites to confirm that the passive remediation strategy is working. Verification monitoring was proposed in the EA for the Riverton site. A certification report, not yet completed for Riverton, is prepared for active and passive remediation sites to document that actions required in the Ground-Water Compliance Action Plan were successfully completed and that the site meets EPA standards. After the certification report is issued, the site will be transferred to the Long Term Surveillance and Maintenance Program.

The NRC has primary responsibility for ensuring that the DOE completes its obligations. States and Tribes have review of DOE actions, but none of these documents or actions requires the concurrence of the Tribes. The involvement of Indian Tribes in the UMTRA Program is defined through individual cooperative agreements negotiated between the DOE and the Tribes. These agreements establish the funding, real estate activities, and technical review requirements needed to perform the remedial action (DOE, PEIS, 1996). The DOE asserts in the PEIS that existing cooperative agreements for the Surface Program are valid, and cover current activities at the site, but note that new agreements will incorporate issues specific to groundwater activities. A cooperative agreement covering groundwater activities at the Riverton Site is not currently in effect between the Tribes and the DOE.

3.6.3 Institutional Controls

Institutional controls are typically used either to control access and exposure to contaminated groundwater or land or to preclude inappropriate land uses. Institutional controls can be active or passive. Fences and signs prohibiting/limiting access are passive institutional controls. An enforcement agency to insure compliance with signs and fences is an active institutional control. One of the most common forms of institutional controls is a deed restriction. Institutional controls include zoning restrictions, use permits, well drilling restrictions, as well as other restrictions that can be administered under local government authority. A specific property owner can use deed restrictions, easements, and restrictive covenants based on state property law on his property to control use. In the case of Riverton, for the purposes of achieving a natural flushing compliance strategy, precluding exposure to contaminated water would be an institutional control.

Institutional controls are only effective in preventing exposure if the control is maintained for the requisite period of time. In order for this to occur, institutional controls need to be "managed". Institutional management is the process used to monitor the effectiveness of institutional controls over time. Effective institutional management must include adequate resources such as funding and personnel to ensure the institutional controls remain in place. For example, to be effective, deed restrictions need to be enforced. Therefore, adequate funding and personnel needs to be ensured to enforcement agencies. In addition, effective institutional management must include monitoring land use changes or actions that have the potential to impact the in-place institutional controls. An example of this would be a detrimental change in groundwater gradients due to nearby groundwater pumping or other dewatering such as gravel pits. Changes that affect the efficacy of the institutional controls, such as water use or dewatering by gravel operations that influence groundwater gradients and flow patterns, must be assessed regularly. The specifics of the institutional management plan for a site may need to be revised to accommodate the changes and ensure that the institutional control remains effective.

3.6.3.1 Use of Institutional Controls with Respect to Compliance with EPA Standard

40 CFR 192 (EPA, 1995), final groundwater regulations for the UMTRA groundwater program, allow for the use of natural attenuation, also known as natural flushing or MNA, as a

remediation strategy under certain specific circumstances. Excerpts from the final EPA groundwater regulations on institutional controls are as follows:

- Application of Institutional Controls During an Extended Remedial Period

  ". . . the regulations permit institutional controls to be used in place of remediation only when DOE is able to ensure their effectiveness will be maintained during their use. The standards require that institutional controls...effectively protect public health and the environment and satisfy beneficial uses of groundwater...during their period of application. In this regard, we note that tribal, state, and local governments can also play a key role in assuring the effectiveness of institutional controls."

- Natural Restoration

  "EPA believes that the use of natural restoration can be a viable alternative in situations where water use and ecological considerations are not affected, and cleanup will occur within a reasonable time. We have concluded that institutional controls, when enforced by government entities, or that otherwise have a high degree of permanence, can be relied on for periods of time up to 100 years, and that adequate safeguards are provided through NRC oversight of the implementation of these standards..."

- Cleanup Standard

  ". . . this rule permits extension of the remedial period to that time, provided institutional control and an adequate verification plan which assures satisfaction of beneficial uses is established and maintained throughout this extended remedial period."

  "Any institutional control that may be required to effectively protect public health and the environment and assure that beneficial uses that the water could have satisfied are provided for in the interim must be verified for effectiveness and modified as necessary."

"The effectiveness of institutional controls must be verified and maintained over the entire period of time that they are in use."

EPA 40 CFR 192 (EPA, 1995) states the following:

Subpart B - 192.12 Standards

(B) *Institutional controls, having a high degree of permanence and which will effectively protect public health and the environment and satisfy beneficial uses of groundwater during the extended period and which is enforceable by the administrative or judicial branches of government entities, is instituted and maintained, as part of the remedial action, at the processing site and wherever contamination by listed constituents from residual radioactive materials is found in groundwater, or is projected to be found, and*

(C) *The groundwater is not currently and is not now projected to become a source for a public water system subject to the provisions of the Safe Drinking Water Act during the extended period.*

The regulations further add that compliance shall be demonstrated through a monitoring program. Environmental data were collected during the site investigation phase, and yearly monitoring has been conducted (DOE, EA, 1998b). Once the Riverton Site enters the LTSM Program, annual inspections and environmental monitoring should be conducted. The environmental monitoring, per LTSM Program guidance, explicitly requires the collection of environmental data to provide an indication of any problems that develop (DOE, 2002) but does not stipulate exactly what data will be collected at which site. A review of the proposed environmental monitoring component of the LTSM plan for the Riverton Site would provide information on whether appropriate types and levels of monitoring are planned for the long-term.

3.6.4 Long-Term Surveillance and Monitoring Program

The DOE created the LTSM Program, which is managed from Grand Junction, Colorado, separately from the UMTRA Project, in 1998 to provide long-term care for low level radioactive materials disposal sites that have been remediated and ensure cost minimization and uniform compliance with applicable regulations and agreements. For a site to be eligible for the LTSM Program, the DOE follows the UMTRA program's process of investigation and remediation, and then the DOE provides the relevant information to the NRC. Once the NRC agrees that the process has been followed and the site is remediated, the NRC issues a license for long-term care and the site enters the LTSM Program. The Riverton site will eventually go into the LTSM program where DOE maintains custody of the site and annual inspections are completed and environmental monitoring is conducted. Each site should have cooperative agreements between the DOE and tribes, states, or former licensees that provide direction on notifying, reporting, and other actions as appropriate (DOE, 2001).

The LTSM Program consists of the following four elements:

- Site monitoring, maintenance, and reporting: includes periodic inspections to verify that engineered structures constructed to isolate hazards from the environment are still intact and perform repairs and maintenance as needed. This specific element is primarily relevant to UMTRA sites with engineered tailings disposal cells. No such structure is present at Riverton.

- Institutional controls: institutional controls that prevent or control exposure to hazards at the site remain in place during the time the site is in the LTSM Program.

- Information and records management: information pertaining to the site is stored and preserved for use by the DOE, the general public and other stakeholders.

- Environmental monitoring: monitoring of air, surface water, groundwater, vegetation, soil, sediment, and wildlife assessments can be conducted to verify continued remedy performance and indicate if any problems are developing.

3.6.5 Institutional Controls and the LTSM Program at the Riverton Site

DOE contends that the Riverton Site has been remediated, a baseline risk assessment has been completed, institutional controls effectively preventing exposure to residual groundwater impacts that will decrease in time through natural flushing have been implemented, public notifications and meetings have been held, and the site is scheduled to enter the LTSM Program in 2004. The following comments are based on information provided in the Riverton SOWP

(DOE, 1998a), the EA (DOE, 1998b); and the NEPA required Riverton Public Participation Plan (DOE, 1998c). The comments focus on the DOE's adherence to the governing regulations and the site-specific handling of regulatory issues.

Section 1.4 of the SOWP (DOE, 1998a) states:

> *"A program will be devised to evaluate and calibrate the rate of natural attenuation and assess the effectiveness of institutional controls. This will be managed by the DOE Long-Term Surveillance and Maintenance Program."*

This statement raises a number of questions that are not addressed in the SOWP. There is no documentation of the above-referenced program that evaluates and calibrates the rate of natural attenuation and that assesses the institutional control's effectiveness. The implication of this statement is that the program will be devised prior to the hand off of the project to the long-term care program. More importantly, there is no information detailing the criteria that would be used to assess the effectiveness of the institutional controls.

3.6.5.1 Efficacy of Institutional Controls

A comment on page 14 of the DOE (EA, 1998b) document states:

> *"Institutional controls such as placing restrictions on access and use would prevent withdrawal of water from the contaminated portion of the surficial aquifer for domestic use."*

This statement is true, but has been ignored; there is no evidence that effective restrictions are in place.

The EA (DOE, 1998b) goes on to state that:

> *"All domestic water near the site is currently taken from the deeper confined aquifer. Water lines at residences that use the confined aquifer will be disconnected and tied to the new water supply lines."*

No evidence has been provided that these disconnections have taken place. More importantly, these disconnections were not mandatory and there are no assurances that the disconnections could not be reversed. If the disconnections of existing confined aquifer wells did not occur, impacted groundwater could be accessed and used as a drinking water supply.

In a discussion on the alternative water supply, DOE (EA, 1998b) states the following:

> *"The water is supplied to eliminate the possibility of using contaminated groundwater in the surficial aquifer as a drinking water source."*

While providing an alternative water source is a good first step, simply providing a water supply is generally not sufficient to eliminate the human use of contaminated groundwater. Institutional controls, such as moratoriums on well drilling, mandatory hook up to the water supply system, plugging and abandoning existing wells, and assurances of the continued maintenance and operation of the water supply system for the natural flushing period would be needed to meet the requirements of the EPA standards. There are no institutional controls such as these in place at Riverton.

The EA (DOE, 1998b) states that:

> *"Institutional controls at the Riverton site would include the alternative water supply system being constructed by IHS. Reservation authorities have agreed to place restrictions on use of groundwater in the contaminated portion of the surficial aquifer and to place a moratorium on drilling permits issued for the affected area."*

There are no restrictions in-place, and there is no well drilling moratorium. A moratorium is mentioned in the MOA on the water supply system. Regardless of the lack of a Tribal moratorium on well drilling, the issue of lands affected by contamination that are potentially under the jurisdiction of the state of Wyoming has never been addressed by DOE. In addition, there is no information available indicating that DOE has ever discussed this with the Wyoming State Engineers Office (SEO). Additionally, the SEO does not have the legal authority to preclude drilling in contaminated aquifers within Wyoming. The SEO can only enter into informal agreements, which do not have the force of law. This means that DOE's groundwater compliance strategy for the Riverton site does not achieve the EPA requirements as set forth in 40 CFR 192.

The EA (DOE, 1998b) maintains the following:

> *"Because some contamination would remain in the uppermost aquifer during the period of natural flushing, institutional controls would be implemented throughout the surficial aquifer from the mill site southeast to the Little Wind River. These controls would consist of construction and maintenance of the alternative supply of potable water for residents near the site, restrictions on the use of contaminated groundwater and a moratorium on drilling new wells in the contaminated aquifer. Although use of groundwater during the natural flushing period could result in adverse human-health and ecological effects as discussed in the BLRA, the risk would lessen over time."*

As stated earlier, there are no restrictions or moratoriums in place. Moreover, there is no evidence that anything has been done to ensure that other needed institutional controls are in place for the Riverton site. Additionally, it is understood that contaminated lands that the state of Wyoming may have jurisdiction over cannot have a moratorium on well drilling, as there is no legal mechanism in place to enforce such a moratorium.

Additionally, there is no evidence that actions have been taken to ensure the continued operation and maintenance of the water supply system. In order for the water supply to be effective, irrespective of the presence or lack of other institutional controls, funds needed for the continued operation and maintenance of the water supply system throughout the natural flushing period should be provided. However, there is no evidence that DOE has provided the appropriate funding for this.

This statement is presented in the DOE (EA, 1998b):

> *"Human health would be protected by the natural flushing alternative. Groundwater in the uppermost aquifer has not been used historically as a source of domestic or drinking water. Through an agreement with the tribes and DOE, IHS has placed a moratorium on drilling in the area of the contaminant plume and is currently constructing an alternate water supply system...Therefore, residential use of groundwater from the surficial aquifer will not be a concern."*

The IHS does not have the authority to place a moratorium on well drilling on Tribal lands. The only entities that have that authority are the Water Resources Control Board and the Joint Tribal Business Council (JTBC). As a result, additional wells could have been installed or could be installed in the future in the area of the groundwater plume and direct exposure to contaminants in groundwater could occur. Additionally, as previously mentioned, this does not take into account additional lands potentially regulated by the state of Wyoming. In summary, there was no information available indicating that entities with the authority to place a moratorium on well drilling were approached by the DOE and that an effective moratorium is in place.

As was the case in the EA, there are numerous references in DOE (SOWP, 1998a) to the use of institutional controls to prevent use of the contaminated groundwater during the remediation period. Section 5.3 of DOE (SOWP, 1998a) provides the following concise summary of the approach adopted to address groundwater contamination and control use:

> *"The compliance strategy presented in this final SOWP includes the implementation of institutional controls on groundwater use near the Riverton site.*

Because implementing this strategy addresses the reduction of contaminant concentrations through time, controlling groundwater use will mitigate the immediate and long-term risks to both public health and the environment."

However, as discussed earlier, there are no effective "institutional controls on groundwater use".

The Public Participation Plan (DOE, 1998c) states the following:

> *"Through an interagency agreement with the Indian Health Services, DOE provided funding for an alternate water supply for residents who live near the site and may be affected by contaminated groundwater. The alternate water supply will serve as an institutional control to eliminate use of the contaminated groundwater during the natural flushing process. Existing domestic wells will be disconnected and water will be provided continually from an engineered municipal water source operated by the tribes."*

The statement above implies that the alternate water supply is the only institutional control that is needed to preclude use of contaminated groundwater. The provision of an alternate water supply without management and operational funding is not an appropriate institutional control. There is also no information provided to support the statement that the water will be provided continually when it does not appear that the DOE has provided funding for continued operation and maintenance of the water supply.

The February 1997 MOA among the IHS and the Northern Arapaho Tribe and the Northern Arapaho Utility Organization, Wind River Indian Reservation, Wyoming, describes the roles and responsibilities of the various parties involved in the expansion of the existing water supply system. In Section 10, dealing with Institutional Control--Moratorium on Domestic Wells in the DOE Project Area, it states:

> *"That the tribe and the Indian Health Service agree not to drill any domestic wells in the project area until such time as Tribal and Federal regulatory agencies have determine the groundwater meets applicable standards for domestic consumption. Both parties agree to take all necessary and appropriate actions*

within their power to support and implement a regulatory moratorium or other appropriate institutional control on the inappropriate use of contaminated groundwater in the Project Area, recognizing that such regulatory action is properly within the jurisdiction of the Water Resources Control Board of the Wind River Indian Reservation."

There are several significant issues associated with the MOA. The compliance strategy for the Riverton site is based on the need to obtain substantive institutional controls to prevent exposure to contaminated groundwater and other associated contamination. The only documentation that describes a moratorium is found in an obscure section in an MOA that DOE was not even a party to. The language above is too vague to provide much assistance in developing not only a moratorium, but is even more vague in describing the need for other institutional controls, such as requiring mandatory hookups to the water supply. Another important point is that the above language does not address the issue of potentially requiring the abandonment of existing wells. Hence, existing wells are not covered even if there were an in-place moratorium, so exposure to contaminated groundwater could easily occur.

While the Chairman of the Arapaho Tribe signed the MOA in 1997, it is our understanding that a moratorium to preclude well drilling as well as other needed institutional controls would need the approval of the JTBC. There is no known documentation that the concept of a moratorium was ever presented to the JTBC by the DOE. It appears the DOE has done little to work with the Tribes on the appropriate language for not only a moratorium, but also for other needed institutional controls. Instead, there is reliance on an obscure document calling for a moratorium signed by people who do not have the authority to implement the requisite institutional controls.

The DOE (1999a) states:

"The ability to ensure the effectiveness of institutional controls over extended time period will be an important consideration."

However, there is no documentation supporting the effectiveness of any institutional controls either in the short or long term.

3.6.5.2 Long-Term Monitoring Issues

Page 7 of the EA (DOE, 1998b) states that the DOE is attempting to negotiate a cooperative agreement with the Northern Arapaho and Shoshone Tribes for groundwater compliance activities. However, while the DOE did attempt to enter into a cooperative agreement with the tribes, the agreement was never signed due to concerns expressed by the tribes. Typically, the cooperative agreement serves as a mechanism for allowing DOE access to conduct studies, including water sampling. Without a cooperative agreement and no other formal documents granting the DOE access to Tribal lands, the DOE groundwater program is most likely in trespass on Tribal lands.

DOE's statement:

> *"Groundwater and surface-water locations would be monitored yearly for 5 years, then once every 5 years thereafter,"*

is provided in the EA as evidence that the DOE intends to monitor groundwater quality and evaluate the effectiveness of natural flushing in restoration. This statement implies that DOE has already made up its mind that natural flushing will work, and no information supporting the choice of five years is provided. This also implies that DOE assumes that the sole institutional control they implemented, an alternate water supply, is sufficient for the duration of the natural flushing period and that additional monitoring for land use changes, etc., will not be needed, and if they are, five-year periods are sufficient. This assumes that the Riverton site is a stable environment and not a dynamic environment. However, since the Little Wind River changed course to create the Oxbow Lake in 1994, this assumption of stability appears to be erroneous.

Page 10 of the DOE (EA, 1998b) states the following:

> *"At each sampling location, when analytical data from three successive annual rounds of sampling indicate that contaminant concentrations have decreased to MCLs, ACLs* [Alternative Concentration Limits] *or background, sampling will be discontinued at that location."*

In the EA, statistical significance and appropriate data validation are not mentioned. Statistical analysis of the groundwater data and assurance that the groundwater data are valid and accurate is important in ensuring that the DOE compliance strategy is working.

DOE (EA, 1998b) does not mention the presence of threatened or endangered (T&E) species in the vicinity of the Riverton site but does say that:

"Groundwater monitoring would not disrupt habitat or vegetation."

It is presumed that the last survey for the presence of T&E species was conducted for the surface EA in the 1980s. While groundwater monitoring would not or should not disrupt habitat, there is no mention of the potential impact of contaminating habitat with contaminated groundwater (such as the Oxbow Lake). It does not appear that the groundwater EA provides sufficient information to determine the potential for the proposed remedial action (i.e., natural flushing) to impact T&E species.

While the EA (1998b) says the following:

"Groundwater would not be used as irrigation in sufficient quantities to cause contaminant build up in soil."

The information used to arrive at this decision is not presented in support of the conclusion. In addition, sufficient quantities are not defined. Contaminant buildup in soil could cause significant adverse impacts directly to vegetation and indirectly to livestock that ingest the vegetation affected by contaminant buildup in soil.

DOE (EA, 1998b) mentions the recently formed Oxbow Lake. Nowhere in the EA or any of the other documents reviewed has DOE taken potential or existing changes in the course of the Little Wind River throughout the natural flushing period into account. This is particularly important since the river changed course in 1994, which created the Oxbow Lake. This oversight is significant since it implies that DOE has never considered the potential for the river to change course and, hence, potentially and significantly impacting the natural flushing compliance strategy. Depending on the nature of the course change of the river, institutional controls could be adversely affected. Moreover, it demonstrates that fact that DOE has no intention of monitoring local land use changes throughout the natural flushing period.

Two DOE documents (1999a and b) on monitored natural attenuation were reviewed. While these two guidance documents came out after the final SOWP and EA (both published in 1998), it should be noted that both documents are based on EPA guidance that has existed since the mid-1990s. Moreover, much of the DOE guidance in these two documents is based on good science and best professional judgment. The text below provides some relevant examples.

The Decision Framework states that monitoring is imperative to:

> *". . . detect unacceptable migration of contamination so that contingency measures can be implemented to prevent any unacceptable risks to human health and the environment" and DOE should "manage uncertainties through contingency planning." The Technical Guidance states, "A primary tenet of monitored natural attenuation is that contingencies are identified and ready for implementation should monitoring data indicate that conditions differ significantly from those assumed . . ."*

There is no evidence of the development of a contingency plan in the event of the failure of the concept of natural attenuation at the Riverton site. Given that there are no effective institutional controls currently in place at the Riverton site, there is concern it does not appear that the remedial action is not performing as planned and that a contingency plan should be implemented immediately.

The issue of uncertainty is significant, particularly when considering the long-term time frame of 100 years for natural flushing. There is no information on how DOE will manage or deal with uncertainties at the Riverton site that may affect the efficacy of the natural flushing remediation. This is, in fact, implied in the Decision Framework in the statement "decisions in situations where future use uncertainties are significant will be more difficult".

The DOE (1999a) states that DOE should "detect any changes in environmental conditions that may reduce the efficacy of natural attenuation processes". The Technical

Guidance (DOE, 1999b) states the following: (1) "must fully consider the temporal variability of those parameters affecting attenuation; i.e., it will be necessary to consider both present and future conditions" and (2) "Therefore, the long-term effectiveness of monitored natural attenuation requires the site and surrounding natural and anthropogenic conditions not change to the extent that natural attenuation processes are not longer effective".

The ability to detect and respond to potential changes in environmental conditions is an important tenet in considering the efficacy of institutional controls. It is not clear that there are any mechanisms in place for detecting potentially detrimental changes in the local environment. Of significant note is the recent development of a gravel pit proximal to the groundwater plume, east of the site (Figure 4). If DOE had a mechanism in place for detecting changes in the local environment, it should have considered the impact that the recently developed gravel pit would have on protecting human health and the environment and should have communicated that analysis to the tribes.

3.6.6 Applicability of Monitored Natural Attenuation

3.6.6.1 Monitored Natural Attenuation and the Safe Drinking Water Act

An EPA requirement, provided in C Subpart B-192.12 Standards of 40 CFR 192, is that groundwater where MNA or natural flushing is implemented as the remedial action should not be currently, or projected to be in the future, a source for a public water system (see Section 3.6.2.1). DOE assumed that the unconfined aquifer and the semi-confined aquifer at the Riverton Site would not serve as a public water supply source and used poor background quality (i.e., high mineral content and high TDS) in support of its contention. The DOE contends that the confined aquifer has not been impacted by site operations and will not be adversely affected in the future. The BLRA (DOE, 1995) states that wells completed in the confined aquifer do supply water for domestic use. There are public supply wells in the confined aquifer in the near vicinity of the site (personal communication, 2002, Wind River Environmental Quality Commission). Therefore, the implementation of MNA is in violation of the requirement that groundwater not be a source for a public water system. If the groundwater in the confined aquifer is considered capable of supporting a public water supply and it did become contaminated, MNA or natural flushing could then be eliminated as an appropriate remedial strategy for groundwater. However, if the confined aquifer is not impacted and not in hydraulic connection with other contaminated groundwater, the strategy DOE has proposed appears to be in line with EPA guidance and regulations. However, knowing the confined aquifer is used as a public source, implementing safeguards to ensure that the confined aquifer does not become impacted would be prudent to protect human health.

3.6.6.2 DOE Compliance with EPA Regulations

The EA (DOE, 1998b) states that if groundwater contaminated with molybdenum were used continuously for irrigation, it would be detrimental to livestock. This means that the presence of this contamination in groundwater does not protect beneficial uses of the groundwater, in this case livestock watering, and does not comply with the regulations detailed in 40 CFR 192.

The DOE (EA, 1998b) contends that:

> *"The strategy is selected on the basis of groundwater regulations and an evaluation of risks to human health and ecological receptors as a result of exposure to groundwater contaminants at the site."*

A review of information provided in the EA, as well as other documents relevant to this site, indicate that this statement is inaccurate for a number of reasons. First, it does not appear that the EPA groundwater regulations have been met, as there are no robust institutional controls to prevent human consumption of contaminated groundwater. Second, as mentioned previously, the molybdenum contamination in groundwater appears to affect the beneficial use of the aquifer for livestock use. Third, there are no institutional controls in place that prevent exposure to contaminated water or sediments in the Oxbow Lake, an area that DOE admits has high levels of contamination. This could be significant since it has been reported that children have been using the lake for swimming. Therefore, exposure to contaminants in water and sediment could occur, possibly resulting in adverse health effects.

With respect to the issue of environmental justice, the DOE (EA, 1998b) states that

> *"The proposed action would not adversely affect groundwater, surface water, land or water use, ecological resources, or wetlands. The application of*

natural flushing and institutional controls would be protective of human health and the environment. The alternate water supply system would eliminate the potential for using contaminated groundwater for drinking water. Although a population that is subject to environmental justice considerations is present at the Riverton site, no disproportionate adverse effects to that population would result from the proposed action."

Considering a number of the points presented above, this statement appears to be inaccurate because available data indicate that DOE has not taken the necessary steps to ensure protection of human health and environment in its selection of natural flushing as a groundwater remedy.

DOE (1999a) also states, citing EPA guidance, that the DOE must include an evaluation of "the reliability of monitoring and institutional controls and provisions for adequate funding to ensure their continuance". As discussed earlier, evidence of this evaluation has not been provided.

The Public Participation Plan (DOE, 1998c) provides a timetable for the scheduled activities for the Riverton Site required in the UMTRA Groundwater Program. Per the timetable, the submittal of documents to stakeholders, public meetings (as needed), the addressing of comments, and provision of the EA in public libraries all took place in a three-month period in 1998. It appears the public participation process was followed; however, the lack of a cooperative agreement with the DOE has unavoidably limited the Tribes involvement.

4.0 SUMMARY OF FINDINGS

This section summarizes the significant findings resulting from Maxim's review of the available technical information. With the exception of DOE, Surface RAP, 1987; DOE 1989; and DOE 1991, Maxim did not review any surface remediation data or reports.

4.1 Surface Remediation

- Data reviewed indicate that verification sampling following surface remediation activities at the Riverton Site was conducted according to the 5 and 15 pCi/g guidelines for Ra-226 as prescribed in 40 CFR guidelines.
- However, when Th-230 was encountered in soil at depth, modifications to the RAP were made and described in Attachment 1 of DOE (Surface RAP, 1987), which prescribed alternative guidelines to deal with Th-230 concentrations both in the saturated zone and unsaturated zones.
- Th-230 concentrations reported in soil samples collected in the unsaturated zone were reduced by determining cobbles-to-fines ratios in the samples, then assuming that Th-230 is concentrated in the fines, and reducing the overall Th-230 levels by the relative volume of coarse material in the sampled stratum. This approach may underestimate the Th-230 concentrations left in soil.
- Th-230 containing material in the saturated zone was left in place regardless of concentration due to the assumption that environmental harm resulting from excavation would outweigh "insignificant" (Attachment 1, Page 4) health benefits realized by removing the material.
- The environmental harm specified in Attachment 1 consists of:

> *"The saturated zone consists of cobbly material with approximately 26% fines (smaller than #4 mesh). Excavation into the saturated zone would be followed by backfilling with soil consisting entirely of fines from the borrow area, which would have different hydrological properties than the in-situ cobbly material. This would impact the location and the flow of water in the shallow aquifer. The*

changes in this aquifer may cause environmental harm; however, this harm cannot be quantified."

- Validity of DOE's statement relative to potential human health concerns from Th-230 contamination left in place is unsubstantiated.

- Two grids, H-45-11 and H-45-16, after all correction factors were applied, were left unexcavated. DOE expectations of backfill diffusion coefficients were factored into mitigation of potential impacts from the two areas to human health and the environment. DOE decided to place title restrictions on the property to prohibit excavation or other disturbance of on-site backfill to ensure protection of human health and the environment. However, Maxim could find no confirmation of placement of these restrictions in the documents.

- This report does not include an evaluation of vicinity property remediation activities, as those data were not available to Maxim.

4.2 Hydrogeology

- The DOE's site conceptual model is either not fully supported by the data or is an interpretation based on a small amount of data.

- The lithology of the five water-bearing units was not accurately depicted. The extent of impacts is unknown due to lateral and vertical data gaps.

- DOE failed to identify preferential flow paths. Interpretation of data from wells 707 and 722 does not accurately characterize contaminant migration pathways.

- DOE failed to account for heterogeneities in the groundwater system, as required by DOE's own guidance. Well spacing was inadequate to describe specific anomalies, such as paleochannels.

- At some depth beneath the surficial aquifer, the groundwater no longer discharges into the river and must flow downgradient under the Little Wind River channel. DOE has not adequately addressed this question. The data available for understanding the flow path of the water in the semi-confined aquifer are insufficient to clearly confirm or refute that this water flushes to the Little Wind River along with the water in the surficial aquifer.

- Water level survey data defining flows between groundwater and the River is missing.

- DOE assumptions about the rate of sedimentation of the Oxbow Lake are contrary to scientific literature. The life of the Oxbow Lake at Riverton is likely to be longer than the DOE projected 100-year life of the natural flushing scenario.

- The DOE maintains that the confined aquifer remains uncontaminated. Existing data are insufficient to support DOE's contention that the confined aquifer is uncontaminated.

4.3 Fate and Transport

- Some data suggest that contaminants in the semiconfined aquifer have been/or are migrating under the Little Wind River.

- The conceptual model used by the DOE does not account for evaporation and dilution in surface water. A conceptual model that does not take evaporation and dilution into account when drawing conclusions could have dangerous consequences for people exposed to surface water, because evaporation has the potential to increase concentrations of contaminants to very high levels.

- Details of sediment and vegetation sampling methods and procedures have not been provided, making it difficult to evaluate data.

- Based on the information presented, there is insufficient background data to make predictions concerning contamination levels in sediment and vegetation.

- DOE did not consider changes in groundwater pH. As conditions become more neutral, there is a potential for an arsenic 'bloom' in the groundwater. Arsenic that had been adsorbed to soil under the low pH acidic conditions will likely desorb and enter groundwater following flushing by more neutral pH water. Arsenic concentrations in groundwater will rise as this occurs. Therefore, arsenic concentrations in groundwater could certainly increase due to pH changes. This potential for an arsenic bloom should be considered and arsenic should be retained as a constituent of potential concern.

- DOE did not consider variations in the distribution coefficient used in its contaminant transport model. Consequently, DOE's prediction for molybdenum flushing within 100 years cannot be supported.

4.4 Groundwater Modeling

The DOE used the results of their modeling analysis to support the selection of natural flushing for correcting groundwater contamination at the Riverton site. Modeling issues that should have been addressed to evaluate whether natural flushing will adequately correct groundwater contamination are as follows:

- Little hydraulic conductivity data was collected along the main plume path.

- Distribution choices used in the modeling effort are not all clearly justified.

- Semi-variogram parameters reported in text do not match figure.

- Description of geostatistical simulator usage is not consistent with its documentation.

- The DOE model employed a uniform Kd field. However, a uniform Kd field does not recognize that low hydraulic conductivity areas are due to fine grained and clayey material, which will have higher Kd.

- Using a probabilistic method, particularly with a sparse database such as that at Riverton, does not remove the need to investigate the impacts of distribution type and limits.

4.5 Risk Assessment

- The site was not adequately characterized prior to completing the BLRA. Several conclusions in the BLRA are based on insufficient data.
- The potential risks associated with drinking water from the semi-confined aquifer are not quantified for livestock (known to occur) and people (potential exists for this to occur) in the BLRA.
- DOE did not have sufficient background data to identify all the appropriate COPC to be considered in the BLRA.
- DOE failed to quantitative evaluate any complete, or potentially complete, exposure pathways except drinking water.
- DOE failed to calculate cumulative risks for specific receptors exposed to contaminants via more than one exposure pathway.
- Site- and receptor-specific exposure assumptions for this site and this Native American population were not used in the quantification of potential risks. Cultural influences were not considered in the selection of exposure parameters.
- The potential for synergistic and antagonistic effects for the COPCs found here were not evaluated.
- The environmental evaluation is inadequate. A screening evaluation, standing alone, cannot ascertain impacts to aquatic life and people eating aquatic life potentially exposed to contaminants.
- There is a paucity of sediment data. Conclusions based on the evaluation of sediment data are, therefore, tentative.
- DOE has not adequately addressed human exposure at the Oxbow Lake.

- Because of false assumptions about the integrity of the confined aquifer, DOE has neglected to address the potential contamination to the large number of domestic wells completed in the confined aquifer.

4.6 Regulatory Issues

- There is currently no cooperative agreement between the tribes and the DOE, allowing DOE to conduct monitoring activities on Tribal lands.

- The presence of molybdenum contamination in the groundwater may not protect beneficial uses (livestock watering) of the groundwater.

- There is no information detailing the criteria that would be used to assess the effectiveness of the institutional controls.

- There are a number of issues related to the effectiveness of in-place institutional controls as required in 40 CFR 192. With the exception of the alternate water supply, there are no additional in-place institutional controls to prevent exposure to contaminated groundwater. In addition, there are no requirements for mandatory hookups to the alternate water supply and well abandonment in the area of groundwater contamination has not been required. Use of impacted groundwater could still be occurring. There is no evidence of a plan for the DOE to provide funding for operation and maintenance of the alternate water supply during the natural flushing period. It appears that no discussions were ever held with the Tribes, including the JTBC and the state of Wyoming, regarding additional institutional controls. There is no documentation that the WRCB was ever contacted about a moratorium.

- It appears that DOE is only monitoring groundwater and not land use changes and other changes that could affect the groundwater gradient and the migration of contaminants in groundwater.

- There is no well drilling moratorium. Wells drill on tribal lands after 1983 require the tribes and the Wyoming SEO to jointly approve well permits. The SEO does not have the legal authority to issue moratoriums on well drilling. Therefore, moratoriums on well drilling do not appear to be a viable institutional control in Wyoming.

- There is no information provided in DOE (EA, 1998b) regarding the potential for contaminated groundwater to contaminate threatened and endangered species habitat and inadequate documentation to support the contention that groundwater used for irrigation would not cause contaminant buildup in the soil.

- DOE (EA, 1998a) states that a program to evaluate and calibrate the rate of attenuation and the effectiveness of the institutional controls will be implemented. However, there does not appear to be a program in place and no criteria defined that would be used to judge the effectiveness of institutional controls. There is no evidence that there is a contingency plan in place, per DOE guidance, in the event that the natural flushing compliance strategy fails. The one in-place control does not appear effective enough to eliminate exposure to groundwater.

5.0 REFERENCES

American Society of Testing and Materials (ASTM), 1993.

Anderson, M.P., and W.W. Woessner, 1992. *Applied Groundwater Modeling, Simulation of Advective Flow and Transport*, Academic Press, Inc., San Diego, California, 381p.

Bear J., Beljin M.S., and Ross R.R., 1992. *Fundamentals of Ground-Water Monitoring, Ground Water Issue*; EPA/540/S-92/005, US Environmental Protection Agency, 11p.

Bloom, Arthur L., 1978. *Geomorphology: A Systematic Analysis of Late Cenozoic Landforms*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 510 p.

Brookins, D.G., 1988. *Eh-pH Diagrams for Geochemistry*. Springer-Verlag, New York, ~~New York~~, 176 pp.

Butler, J.J. Jr., 1998. *Design, Performance, and Analysis of Slug Tests*; Lewis Publishers, Boca Raton, Florida, 262p.

Carrera, J., 1993. *An overview of uncertainties in modeling groundwater solute transport*, J. Cont. Hydrology, 13, 23-48.

Davis, J.A., Fuller, C.C., Coston, J.A., Hess, K.M., and E. Dixon, 1993. *Spatial Heterogeneity of Geochemical and Hydrologic Parameters Affecting Metal Transport in Groundwater*, U.S. EPA, EPA/600/S-93/006.

Deutsch. C.V., and A. G. Journel, 1992. GSLIB, Geostatistical Software Library and Users Guide, Oxford University Press, 340 p.

Faust, C.R., P.N. Sims, C.P. Spalding, P.F. Andersen, B.H. Lester, M.G. Shupe, and A. Harrover, 1994. *FTWORK: Groundwater flow and transport in Three Dimensions*, GeoTrans, Inc.

Gelhar, L. W., (1986), "Stochastic Subsurface Hydrology from Theory to Applications," *Water Resources Research*, 22: 1355-1453.

Isaaks, E.H., and R.M. Srivastava, 1989. *Applied Geostatistics*, Oxford University Press, New York, New York.

Journal, A.G., and Ch. J. Huijbrects, 1978. *Mining Geostatistics*, Academic Press, London; New York, 600 p.

Journel, A., and F. Alabert, 1989. *Non-Gaussian Data Expansion in the Earth Sciences*, Terra Nova, pp. 1:123-24.

Konikow, L., and J. Bredehoeft, 1992. *Ground-water models cannot be validated*, Adv. Water Res., pp. 15, 75-83.

Langmuir, D., 1997. *Aqueous Environmental Chemistry*, Prentice Hall, Upper Saddle River, New Jersey, 600 p.

de Marsily, G., F. Delay, V. Teles, and M. T. Schafmeister, 1998. *Some current methods to represent the heterogeneity of natural media in hydrogeology*, Hydrogeol. J., pp. 6, 115-130.

Memorandum of Agreement (MOA) 1997. Between the Tribes and the DOE.

Mercer, J., 1987, Editorial: *Should proprietary codes be banned for groundwater problems?* Groundwater, 24(5), pp. 691-692.

Merritt, R.C. 1971. *The Extractive Metallurgy of Uranium*. Prepared Under Contract with the U.S. Atomic Energy Commission by the Colorado School of Mines Research Institute.

Nichols, W. and M. Freshley, 1993. *Uncertainty Analyses of Unsaturated Zone Travel Time at Yucca Mountain*, Groundwater, v. 31, no. 2, pp. 293-302.

Oreskes, N., Shrader-Frechette, K., and K. Belitz, 1994. *Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences*, Science, pp. 263.

Peck, A., Gorelick, S., de Marsily, G., Foster, S., and V. Kovalevsky, 1989. *Consequences of Spatial Variability in Aquifer Properties and Data Limitations for Groundwater Modeling Practice*, IAHS Publication No. 175, Washington, DC.

Rai, D., and Zachara, J.M, 1984. *Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration, Volume I: A Critical Review*. EPRI, EA-3356, Research Project 2188-1.

Reineck, H., and Singh, I. B., 1980. *Depositional Sedimentary Environments, With Reference to Terrigenous Clastics*. Springer-Verlag, Berlin Heidelberg New York, 549 p.

Seeland, D.A., 1978. *Sedimentology and Stratigraphy of the Lower Eocene Wind River Formation, Central Wyoming*. In *Resources of the Wind River Basin, Wyoming Geological Association, 30th Annual Field Conference Guidebook*, pp. 181-198.

U.S. Department of Energy (DOE), 1987. *Remedial Action Plan and Site Design for Stabilization of Inactive Uranium Mill Tailings at Riverton, Wyoming, Wyoming*, UMTRA DOE/AL-050507.0000, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1989. *Modifications to the Remedial Action Plan and Site Design for Stabilization of Inactive Uranium Mill Tailings at Riverton, Wyoming, Wyoming*, DOE Contract No. DE-AC04-83AL18796, prepared by the M.K. Ferguson Company, Remedial Action Contractor to UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1991. *Final Completion Report for Remedial Action at the Riverton Uranium Mill Tailings Site, Riverton, Wyoming*, DOE Contract No. DE-AC04-83AL18796, prepared by the M.K. Ferguson Company, Remedial Action Contractor to UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1993. *Technical Approach to Groundwater Restoration,* Final, DOE/AL/62350-20F, November 1993, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1995. *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site Near Riverton, Wyoming,* DOE/AL/62350–64, Rev. 1, Version 3, September 1995, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1996. *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project,* DOE/EIS–0198, October 1996, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1998a. *Final Site Observational Work Plan for the UMTRA Project Site at Riverton, Wyoming*, February 1998, prepared by the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1998b. *Final Environmental Assessment of Ground Water Compliance at the Riverton, Wyoming, Uranium Mill Tailings Site*, prepared by the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1998c. *Public Involvement Plan for the Environmental Assessment of Ground Water Compliance Activities at the Riverton, Wyoming, Uranium Mill Tailings Site,* prepared by the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1999a, "*Decision Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites*" (Decision Framework), dated May 13, 1999

__________, 1999b, *Technical Guidance for Long-Term Monitoring of Natural Attenuation Remedies at DOE Sites (Technical Guidance)* dated October 8, 1999

__________, 2001. *Guidance for Implementing The Long-Term Surveillance Program For UMTRCA Title I and Title II Disposal Sites*, prepared by the U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Environmental Protection Agency (EPA), 1995*Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, U.S. Code of Federal Regulations 40 CFR 192.

__________, 1997. *Guiding Principles for Monte Carlo Analysis*, 630/R-97/001, March 1997, Risk Assessment Forum, Washington, DC 20460.

U.S. Nuclear Regulatory Commission (NRC), 1980. Final Genaric Environmental Impact Statementon Uranium Milling, UREG-0706, U.S. Nuclear Regulatory Commission, Office of Nuclear Material, Washington, D.C.

Woodbury, A., Render, F., and Ulrych, T., 1995. *Practical Probabilistic Ground-Water Modeling*, Groundwater, v. 33, no. 4, pp.532-538.

Zheng, C., and Bennet, G., 1995. *Applied Contaminant Transport Modeling*, Van Nostrand Reinhold.

6.0 MAXIM TECHNICAL STAFF

Carol Baker, Senior Risk Assessor	Risk Assessment, Senior Review
Denise Bierley, Senior Regulatory Compliance Specialist	Regulatory Issues
Robert M. Sengebush, P.G. Senior Hydrogeologist	Hydrogeology, Fluvial Geomorphology
Daniel W. Erskine, Ph.D. Senior Geochemist	Lead Author, Hydrogeology, Fate and Transport
Greg Ruskauff, CGWP, P.Hg., Senior Groundwater Modeler	Review of GANDT Model
Tom Tangen, Senior Environmental Engineer	Review of Surface Remedial Action
Clyde L. Yancey, P.G. Senior Project Manager	Project Manager, Senior Review

7.0 LIST OF DOCUMENTS REVIEWED

Memorandum of Agreement (MOA) 1997. Between the Tribes and the DOE.

U.S. Department of Energy (DOE), 1987a. *Remedial Action Plan and Site Design for Stabilization of Inactive Uranium Mill Tailings at Riverton, Wyoming, Wyoming*, UMTRA DOE/AL-050507.0000, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1987b. *Environmental Assessment for Remedial Action at the Riverton Uranium Mill Tailings Site, Riverton, Wyoming*, DOE/EA-0254, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1989. *Modifications to the Remedial Action Plan and Site Design for Stabilization of Inactive Uranium Mill Tailings at Riverton, Wyoming, Wyoming*, DOE Contract No. DE-AC04-83AL18796, prepared by the M.K. Ferguson Company, Remedial Action Contractor to UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1991. *Final Completion Report for Remedial Action at the Riverton Uranium Mill Tailings Site, Riverton, Wyoming*, DOE Contract No. DE-AC04-83AL18796, prepared by the M.K. Ferguson Company, Remedial Action Contractor to UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1993. *Technical Approach to Groundwater Restoration*, Final, DOE/AL/62350-20F, November 1993, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1993. *Technical Approach to Groundwater Restoration*, Final, DOE/AL/62350-20F, November 1993, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1994. *UMTRA Project Water Sampling and Analysis Plan, Riverton, Wyoming*, DOE/AL/62350-117, prepared by the U.S. Department of Energy, UMTRA Project Office.

__________, 1995a. *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site Near Riverton, Wyoming*, DOE/AL/62350–64, Rev. 1, Version 3, September 1995, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

__________, 1995b. *Supplement to the Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site Near Riverton, Wyoming, Riverton, Wyoming*, DOE/EA-0254, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office. Albuquerque, New Mexico.

TABLES

Table 1. *Private Wells, Details, and Sampling Dates, Riverton Site*

Domestic wells[a] TAC ID No.	Year(s) sampled	Total/casing depth (ft)	Aquifer	Water use[c]
401[b]	1985	NA/NA	NA	NA
402[b]	1985	NA/NA	NA	NA
403[b]	1985	NA/NA	NA	NA
404[b]	1985	NA/NA	NA	NA
405	1981, 1983, 1984(2X), 1985, 1990, 1991(3X), 1992(2X), 1993, 1995, 1997	274/NA	Confined sandstone	Potable
406	1981, 1990, 1991(3X), 1992(2X), 1993, 1995, 1997	350/NA	Confined sandstone	Potable
407[b]	1982	NA/NA	NA	NA
409[b]	1985	NA/NA	NA	NA
410	1982, 1983, 1984(3X), 1990(2X), 1992(2X), 1993, 1995, 1997	100/NA	Confined sandstone	Domestic
411	1985, 1988, 1990, 1991(3X), 1992(2X), 1993, 1997	270/261	Confined sandstone	Domestic
412[b]	1985	NA/NA	NA	NA
413[b]	1985	NA/NA	NA	NA
415[b]	1981, 1983, 1984	NA/NA	NA	NA
417	1981, 1990, 1991, 1992, 1993, 1995, 1997	400/350	Confined sandstone	Potable[e]
420	1981, 1983, 1984(3X), 1985, 1990(2X), 1991(3X), 1992(2X), 1993, 1995, 1997	273/228	Confined sandstone	Potable
421	1981, 1985, 1995	200/NA	Confined sandstone	Potable
422[b]	1984, 1985	NA/NA	NA	NA
423	1984, 1985, 1988, 1990, 1991(3X), 1992(2X), 1993, 1995	290/NA	Confined sandstone	Potable
424[b]	1984	NA/NA	NA	NA
425[b]	1984, 1985	NA/NA	NA	NA
430	1981, 1983, 1984(2X), 1985, 1990, 1991(2X), 1992(2X), 1993, 1995, 1997	320/284	Confined sandstone	Potable
431	1984, 1985, 1992, 1993, 1995, 1996, 1997	Approximately 15 (installed with backhoe)	Surficial	Stock
435[b]	1983, 1984(2X)	NA/NA	NA	NA
436	1982, 1991(3X), 1992(2X), 1993, 1995	525/NA	Confined sandstone	Potable
437[b]	1985	NA/NA	NA	NA
440	1984, 1985(2X), 1988, 1990(2X), 1995, 1997	267/NA	Confined sandstone	Potable[e]

Table 1 (Continued

Domestic wells[a] TAC ID No.	Year(s) sampled	Total/casing depth (ft)	Aquifer	Water use[c]
441	1985, 1995	100/NA	Confined sandstone	Potable*
442	1994, 1995, 1997	405/NA	Confined sandstone	Domestic
443	1994	397/356.5	Confined sandstone	Potable
444	1994, 1995, 1997	375/365	Confined sandstone	Domestic
445	1994, 1997	35/NA	Surficial	Stock
446	1994, 1995, 1997	410/370	Confined sandstone	Potable
448	1994, 1995, 1997	405/NA	Confined sandstone	Potable
451	1994, 1995, 1997	360/338	Confined sandstone	Potable
452	1994, 1995, 1997	NA/NA	NA	Potable
453	1994, 1995, 1997	NA/NA	NA	Potable
460	1984, 1993, 1995	450/NA	Confined sandstone	Process
461	1996	NA/NA	NA	NA
951	1988, 1992(2X)	273/246	NA	Potable*

[a]See Plate 1 for well locations.
[b]These wells were sampled in 1981, 1983, 1984 and/or 1985 only. They are located outside the maximum probable extent of contamination and were not sampled again. Construction details and water uses are not available. They are not located on Plate 1, but analytical data is included in Appendix B.1 for completeness.

[c]Water uses:

Potable	=	Drinking and other uses.
Domestic	=	Bathing, washing dishes and other uses, but not drinking.
Stock	=	Watering livestock, irrigation, but not drinking or domestic.
NA	=	Information not available.
*	=	Where water use is not certain, suggest potable to be conservative.
Process	=	Industrial use.

Water use from interviews with resident or inferred from well characteristics.

Table 2. from Table 4-5 of the BLRA

Table 4.5 Exposure dose calculations for ingesting incidental surface water and fish from the Little Wind River, Riverton, Wyoming, site

Constituent	Csw (mg/L)	Location ID	BCF (L/kg)	Cf (mg/kg)	Surface water ingestion exposure dose (mg/kg-day)	Fish ingestion exposure dose (mg/kg-day)
Noncarcinogenic effects						
Calcium	4.2E+01	796	NA	NA	2E-03	NA
Iron	3.1E+00	796	100	3.1E+02	1E-04	6E-02
Magnesium	1.4E+01	796	NA	NA	5E-04	NA
Manganese	1.4E-01	796	NA	NA	5E-06	NA
Uranium	2.5E-02	742	2.0	5.0E-02	9E-07	1E-05
Carcinogenic effects						
Uranium	1.7E+01[a]	742	2.0	3.4E+01[b]	5E+02[c]	5E+03[c]

[a]In picocuries per liter.
[b]In picocuries per kilogram.
[c]In picocuries per lifetime.
BCF—bioconcentration factor (EPA, 1992a; NUREG, 1986).
NA—BCF not available for this contaminant.